Principles of Disaster Mitigation in Health Facilities

Pan American Health Organization

Regional Office of the
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Disaster Mitigation Series

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Table of Contents

Chapter 3

Chapter 4

Annex

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Their invaluable contributions and observations have made it possible to offer this set of mitigation tools to the countries of Latin America and the Caribbean.

Preface

This book presents key principles of disaster mitigation that can be of value to health facilities throughout the Americas. By compiling this information the Pan American Health Organization, the Regional Office for the Americas of the World Health Organization (PAHO/WHO) hopes to reach national and local authorities, hospital administrators, officials and staff, and other human resources connected in significant ways to health facilities. The book is aimed at health professionals, personnel responsible for health facility operations and maintenance, educators, architects and engineers, and members of the construction industry.

During its first meeting, held in July 1997, the PAHO/WHO International Hospital Mitigation Advisory Committee recommended that publications dealing with hospital mitigation have a multidisciplinary approach and include experiences and case studies from throughout Latin America and the Caribbean. Based on this recommendation, the PAHO Emergency Preparedness and Disaster Relief Coordination Program decided to produce a new and extensively revised edition of Disaster Mitigation in Health Facilities, originally comprised of four volumes: General Issues, Administrative Issues, Architectural Issues, and Engineering Issues. As the titles imply, each volume examined a different facet of disaster mitigation in hospitals, and had a different target audience.

Since the Advisory Group recommended a multidisciplinary approach, the four volumes have been condensed into one. Some of the chapters and sections have been simplified and rewritten for a more general audience, and other graphical elements have been introduced to illustrate key concepts, particularly the factors that increase hospital vulnerability to natural disasters. Case studies from countries in the region describe the methodology employed in various mitigation projects and processes, as well as the results of such initiatives, showing that hospital mitigation is indeed practical and feasible.

One of the most relevant success stories in Latin America and the Caribbean has been the inclusion of disaster mitigation issues in the sectoral reforms underway in a majority of countries, thanks to awareness-raising efforts at the political level. Sectoral authorities can therefore proudly point to the positive results, in terms of cost effectiveness, of incorporating mitigation measures into any process aimed at upgrading health facilities, and health care in general.

This book examines the potential problems that can arise when disasters strike health facilities, and offers specific mitigation measures, emphasizing the key components that have to be in place for health establishments to continue providing vital services during and in the immediate aftermath of a major emergency.

Health facilities can be affected by natural phenomena such as earthquakes, hurricanes, landslides, volcanic eruptions, and floods. They can also be damaged by anthropic (i.e., man-made) events such as fires, gas leaks or explosions. However, the emphasis here will be on seismic events, for two reasons. The first is that no other natural disaster affects health facilities as severely as earthquakes do. The second is that in reducing both the direct and indirect effects of seismic events, practically all other hazards are reduced.

Introduction

The planning, design and construction of health facilities in high-risk areas provide multiple challenges to the professionals involved in these efforts, given the importance of such buildings to the everyday life of a city—particularly when disaster strikes. A community's recovery after a major event depends to a significant extent on the ability of health facilities to function without interruption and to provide the extra care needed during an emergency. Many issues must be considered, ranging from the site chosen for construction to the installation of nonstructural equipment, not to mention the architectural design and structural integrity of the buildings.

Many health facilities have suffered severe damage as a result of natural disasters (particularly high-intensity earthquakes and hurricanes), leading to the partial or total collapse of the structures and the interruption of the health services urgently needed by the victims of the event.

It is in this context that existing regulations on the design and construction of health facilities must be revised. They must be reoriented towards disaster mitigation, with the ultimate goal, not only of protecting the lives of their occupants, but of ensuring that these facilities can continue to function after a disaster strikes.

This book compiles information previously published by PAHO/WHO, covering topics related to potential problems generated by natural events as well as the mitigation measures necessary to ensure that a facility will continue to function during and immediately following an event. It aims to encourage the reader to reflect on the planning, design, construction, operational and maintenance criteria governing health infrastructure. It presents techniques for the identification and assessment of hospital vulnerability. Risk mitigation solutions are presented that will protect both the population and the investments made in building or improving health facilities. The book is not intended to cover in detail technical aspects that have been the subject of academic publications, although the necessary references are included for the benefit of the reader who wishes to study these topics more in depth.

Chapter 1 reviews cases of health facilities affected by disasters in the Americas, including descriptions of the types of damage and, more generally, the losses suffered by health facilities as a result of earthquakes in recent years. Other topics include the role of health facilities in disaster situations, the demand for their services in such situations, and the economic and social costs of not having access to them at such a critical moment. Finally, the types of physical vulnerability found in health facilities are enumerated.

Chapter 2 focuses on structural vulnerability. When vulnerability is high, the essential operations of a health facility may be compromised, lives may be lost, and the facility's assets may be destroyed. The chapter discusses architectural practices that augment structural vulnerability, and provides guidelines on how to perform a vulnerability assessment based on the most widely accepted engineering methods. Additional guidelines explain how the facility's infrastructure can be reinforced through retrofitting or rehabilitation.

The vulnerability of nonstructural elements is the subject of Chapter 3, which discusses the behavior of architectural finishes and of medical and support equipment and installations. Steps are outlined for inventorying and assessing nonstructural vulnerability and carrying out the interventions needed for risk mitigation.

Chapter 4 deals with administrative and organizational vulnerability issues that can interrupt or degrade hospital services after a major event. Key concepts are outlined, including sectoral modernization, decentralization and quality control. These concepts provide the framework for the implementation of sectoral guidelines for disaster mitigation.The wrong administrative and organizational procedures can increase this type of vulnerability; recommendations are made on how to prevent or modify them.

One of the most important topics in this chapter is how to use the various vulnerability assessments of the facilities to perfect disaster preparedness activities until the resources are in place for an intervention. However, the connection between disaster preparedness, on the one hand, and functional and nonstructural aspects on the other, can only be explored here superficially, and readers are encouraged to consult the specialized publications produced by PAHO that are included in the references,[1] and which detail the methodologies required to formulate, test and update hospital emergency plans.

The annex outlines current methods used to analyze the structural vulnerability of hospitals.

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[1] An extensive bibliography on safer hospitals, including relevant publications on hospitals and disaster preparedness, can be found in Bibliodes # 22, September 1995. Bibliodes is published by the Regional Disaster Information Center (CRID), a resource center for disaster mitigation for Latin America and the Caribbean that is partly sponsored by PAHO/WHO and the Secretariat of the International Decade for Natural Disaster Reduction (IDNDR).

Executive Sumary

Hospitals, and health facilities in general, are exposed systems that can suffer severe damage as a result of intense natural phenomena. Given the seriousness of the risk, new health facilities must be built to standards that can help them to withstand the natural hazards that surround them. It is also necessary to assess the vulnerability of existing buildings with a view to identifying their weaknesses, and to plan, design, and carry out the physical interventions or retrofitting needed.

Between 1981 and 1996, a total of 93 hospitals and 538 health centers were significantly damaged as a result of natural disasters in Latin America and the Caribbean. Some collapsed. Others were so weakened that they had to be evacuated. According to the Economic Commission for Latin America and the Caribbean (ECLAC), direct losses in the Region as a result of such events reached US$ 3.12 billion over that period. To visualize such an impact, it helps to imagine 20 countries in the region each suffering the collapse of 6 major hospitals and 25 health centers. This underscores the urgency of reviewing design strategies and construction practices of health facilities located in disaster-prone regions.

> When it comes to disaster mitigation, hospitals require special attention due to the vital functions they perform, their high level of occupaancy, and the role they play during a disaster situation.

At any given moment, hospitals can have a large population of resident patients, outpatients, staff members and visitors. In the event of a disaster, they must continue to treat the patients who were already in their care, while tending to the needs of the injured. For this to happen, the staff must be in place and must know how to respond to the situation. It is just as important, however, for the infrastructure and equipment to remain functional after disaster impact.

The systematic organization and easy mobilization of the staff, equipment and supplies in a safe environment are crucial if disaster response is to be prompt and effective. Buildings, technology and processes are both interdependent and critical. Deficiencies in any of the functional aspects of a hospital can plunge the institution into a crisis.

Moreover, due to the high cost of health facilities and the vital services they provide, major damage can have a severe impact on public finances and the production capacity of a country due to the high costs of repair and reconstruction.

Hospital facilities include clinical services, diagnostic support services and general services, all of which have specific functions and yet must interact for the hospital to operate effectively. The relationship between administration, intermediate or outpatient services, general services, outpatient consultation, emergencies, and inpatient services is critical, and when designing the facilities attention must be paid to their operations and physical distribution in the event that a massive number of patients must be assisted. The areas surrounding the hospital and hospital access routes play a particularly important role in disaster response. A hospital can be the victim of a functional collapse, a danger that is often detected only in the middle of an emergency.

A building may remain standing after a disaster yet be rendered incapable of providing medical care due to nonstructural damage. In most buildings the cost of nonstructural components is considerably higher than that of structural components. This is particularly true of hospitals, where between 85% and 90% of the value of the facilities lies in the architectural elements, the mechanical and electrical systems, and the medical equipment. A seismic event of lesser magnitude, which is far more common than a major earthquake, can damage nonstructural elements. These key components of a hospital, those most directly linked to its purpose and function, are the ones most likely to be affected or destroyed by earthquakes. On the other hand, it is easier and less costly to retrofit them and prevent their destruction or severe degradation.

Many of the problems mentioned above originate in structural and nonstructural safety of the building. The structural components should be considered during the design and construction phase of a new building or during the repair, remodeling, or maintenance of existing buildings. Good structural design is key to a building's survival in an earthquake. Damage may occur, but collapse is unlikely.

Unfortunately, in many countries in Latin America and the Caribbean codes for seismic-resistant buildings have not been followed or have not taken into account the special specifications required by health facilities. Little wonder, then, that every time a major earthquake shakes the region, the most severely damaged buildings will include some hospitals. Hospital vulnerability is high and this must be corrected in order to prevent economic, social and human losses, particularly in developing countries that can ill afford such losses.

Disaster mitigation through the adoption of preventive measures makes economic sense in areas prone to recurring events. For each dollar invested in mitigation before a disaster strikes, enormous savings will be made in losses prevented. Mitigation is ultimately cost-free, since it pays for itself in lives and money saved.

The various mitigation measures have different implementation methods and costs. The simplest and most economical have to do with nonstructural and administrative and organizational aspects; the most complex and costly are the structural measures. If an integrated hospital mitigation plan is carried out in stages, the use of resources can be spaced out over time, making it easier to keep the additional expenses within a reasonable margin of ongoing maintenance costs.

A vulnerability analysis begins with a visual inspection of the facilities and the preparation of a preliminary report. This inspection makes it possible to identify the areas that require attention. The report will be discussed with consultants and hospital authorities in order to set priorities and a timetable for undertaking the work.

In every documented case, cost/benefit analysis has shown the economic and social sense of upgrading the structural and nonstructural behavior of vulnerable hospital buildings. The cost may seem high, but it is always significantly lower than that of repairing or replacing damaged facilities. It is useful to ask questions such as this: how many CT scanners could be bought with the cost of retrofitting the building? And how many of them does the hospital now have? The answer can be surprising, without even considering the other equipment and assets currently housed by the facilities, much less the human lives directly or indirectly at risk due to the current deficiencies and the social cost of losing the services provided by the hospital.

Risk reduction in hospital design is a responsibility shared by architects, engineers, physicians and administrators. The link between architecture and resistant structural systems must be clear to all involved in the design process in disaster-prone areas.

The loss of life and property as a result of an earthquake can be prevented by applying available technology and without great expense. The only thing needed is the will to proceed. With the current understanding of the construction requirements for buildings that can resist earthquakes, hurricanes, and other natural hazards and damage can be minimized as long as the right preventive measures are taken in the design, construction and maintenance of new health facilities.

Recommendations

1. All buildings where health services operate in disaster-prone areas must carry out vulnerability and risk assessments of the structures and essential hospital services.
2. Appropriate mitigation measures must be taken in the design and construction of new health facilities or the remodeling and expansion of existing establishments in accordance with an integrated disaster mitigation plan.
3. Nonstructural mitigation or intervention measures must be included in plans for maintenance, inspection, remodeling, and upgrading existing hospitals.
4. Risk reduction specifications must be met as part of the procedures for acquiring, operating, and maintaining hospital equipment and systems.
5. Hospital disaster preparedness plans must be reviewed to take into account hospital vulnerability.
6. Design and building codes must be enforced in the design and construction of health facilities. They must aim not just to protect the lives of their occupants but also to ensure the uninterrupted operations of the facility after a disaster has struck.
7. Health care administrators, medical staff, builders and maintenance personnel must be made aware of the standards to be met for buildings entrusted to withstand the impact of potential natural disasters.
8. Hospitals must keep up-to-date information and floor plans of their buildings’ architectural, engineering and technical design in a safe and accessible place.

This book, ***Principles of Disaster Mitigation in Health Facilities***, has been prepared by the Pan American Health Organization (PAHO) for national and local authorities, building owners, administrators, health professionals, officials, engineers, architects and other personnel involved in the planning, operations, and management of health services. After describing the kinds of damage that may be expected in the event of a natural disaster, guidelines are provided to incorporate seismic risk mitigation procedures in the inspection of existing establishments and the planning, design, and construction of new structures.

Chapter 1
Disasters and Hospitals

Background

A disaster may be defined as an event or occurrence—usually sudden and unexpected—that intensely alters the beings, objects and localities under its influence. It results in loss of life and health in the local population, causes severe environmental damage and the destruction or loss of material goods resulting in a dramatic disruption of normal patterns of life. Such disruption—which may be local, national or even regional in scope—gives rise to the need for immediate intervention and humanitarian aid.

Disasters may be caused by natural phenomena, human actions, or industrial accidents. Some natural disasters are caused by hazards that cannot be neutralized, because there is no way to control their causes. Earthquakes, volcanic eruptions, tsunamis, and hurricanes are examples of hazards that cannot yet be prevented or diverted. On the other hand, appropriate measures can be taken to control or reduce the impact of other natural events, such as floods, droughts and landslides.

The effects of a disaster vary according to the nature of the event itself and the characteristics of the communities and objects affected: the population, their natural environment, their housing, the public services on which they depend, and the physical structures and assets of industry, commerce, and other economic activities that provide goods and livelihoods.

A disaster causes both direct and indirect losses. The physical destruction caused by a disaster is considered a direct loss, and includes the human victims, environmental degradation (i.e., the alteration of the habitat), and damage to buildings, infrastructure, and urban spaces.

Indirect losses are generally divided into social and economic effects. Social effects include the interruption of transportation, communications (including the mass media), and other public services. They can include the negative image that a country or region might acquire in the wake of a disaster. Economic effects include the cost of reconstruction and rehabilitation, the impact of reduced production or consumption on trade and industry, the potential discouragement or flight of foreign investment, and the lack of access to basic services such as health care.

In many developing countries, such as those of Latin America and the Caribbean, disasters lasting 20 to 30 seconds have caused thousands of deaths and hundreds of millions of dollars in damage. The often incalculable economic costs of the direct and indirect losses from these events can represent an enormous percentage of the country's gross domestic product. Such losses increase poverty among the population and stall or set back economic development at the national or regional level.

In order to reduce existing risk levels, disaster prevention measures must be considered a fundamental part of sustainable regional and urban development. Given the negative impact of disasters on the development of the communities they strike, risk assessment must be incorporated into the key social and economic processes of each country or region, comparing the cost of taking preventive measures with that of disaster recovery. In most cases, prevention is more cost-effective than recovery.

In recent years, many publications in numerous fields have addressed the impact of disasters on human activities. Despite occasional differences, most of these publications agree on the components of disaster impact. The Office of the United Nations Disaster Relief Coordinator (OCHA, formerly known as UNDRO) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) held the Natural Disasters and Vulnerability Assessment meeting to propose uniform definitions that have been widely accepted in recent years. The report from this meeting provided the following definitions:

Hazard (H) is defined as the probability that a potentially disastrous event will occur during a given time period in a given place.

Vulnerability (V) is the level of loss that an element or group of elements—people, structures, goods, services, economic or social capital—that are exposed to risk would experience as a result of the probable occurrence of a disastrous event. Vulnerability is expressed on a scale from 0 (no damage) to 1 (total loss).

Specific Risk (**R_s**) is the level of expected loss as a result of the occurrence of a particular event. It is a function of hazard and vulnerability.

Elements Exposed to Risk (E) includes the local population as well as the buildings, civil works, economic activities, public services, utilities and infrastructure that are exposed in a given geographic area.

Total risk (**R_t**) is a quantification of the human losses, injuries, property damage and impact on economic activity that would result from the occurrence of a disastrous event. It is the product of the specific risk R_s and the elements at risk E.

Risk may therefore be evaluated using the following general formula:

$$R_t = E \times R_s = E(H \times V)$$

where exposure E is considered implicit in vulnerability V.

Given hazard H_i (the probability that an event of intensity greater than or equal to i will occur during a period of exposure t) and vulnerability V_e (the intrinsic predisposition of an exposed element e to suffer impact or loss from the occurrence of an event of intensity i), the risk R_{ie} is understood as the probability of a loss to element e due to the occurrence of an event of intensity greater than or equal to i:

$$R_{ie} = (H_i \times V_e)$$

This expresses the probability that the social and economic consequences or effects will exceed a specific predetermined value during a given time period t.[1]

It is therefore possible to craft a more precise definition of two concepts that are sometimes taken for synonyms, but which are in fact qualitatively and quantitatively different:

- *Hazard* is a risk factor external to a subject or system. It involves a latent or potential danger associated with a physical phenomenon of natural or technological origin that could arise in a specific location over a given span of time, producing adverse effects on people, property, or the environment. Hazard is expressed mathematically as the probability of an event of a given intensity taking place in a given place over a given period of time.

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[1] Cardona, O.D. Estudios de vulnerabilidad y evaluación del riesgo sísmico: planificación física y urbana en áreas propensas. Asociación Colombiana de Ingeniería Sísmica, *Boletín Técnico* No. 33, Bogotá, December 1986.

- *Risk* is the expected level of destruction or loss that will take place given the probability of hazardous events taking place and the level of vulnerability of the elements exposed to these hazards. It is expressed mathematically as the probability that the economic and social consequences of a given event in a certain place over a certain period of time will exceed a given level.

In general terms, *vulnerability* may then be understood as the intrinsic predisposition of a subject or element to suffer damage from potential external events. A vulnerability assessment therefore constitutes a fundamental contribution to the understanding of risk, by analyzing the interactions between susceptible elements and a hazardous environment.

The fundamental difference between hazard and risk is that a hazard is related to the probability that a natural event or one caused by human activity will occur, while a risk is related to the probability that certain circumstances will occur. These circumstances are closely related not only to the elements' level of exposure to an event, but also to their vulnerability to the effects of the event.

Damage to hospitals

The need for health care establishments to be prepared and able to take action in emergency situations is especially critical in Latin America and the Caribbean. In the past, earthquakes, hurricanes and floods (such as those related to the El Niño phenomenon), and other natural hazards have shown hospitals and health establishments to be vulnerable to these disasters, often without the capacity to respond adequately.

Because hospitals play such a vital role in the recovery of a community after an earthquake, many factors must be taken into account when selecting the location of a health facility, as well as when designing, building, maintaining and operating it. These considerations range from structural resistance requirements to disaster response planning to the installation of a range of nonstructural elements and equipment.

Nevertheless, in the wake of intense natural events, many hospitals have ceased to function, suffered serious structural damage or even collapsed, depriving their respective communities of the medical care needed by disaster victims.

Many of the hospitals so affected were designed in accordance with seismic-resistant building codes. The structural design of a hospital requires much greater care than the design of a less crucial building or complex of buildings. Seismic-resistance standards in most Latin American countries are not adequate, because they are frequently based on a philosophy of protecting the lives of the building's occupants, not of guaranteeing the structure's continued functionality (see below).

Philosophy of Existing Seismic Standards

- Structures should withstand events of moderate intensity without damage.
- Damage should be limited to nonstructural elements during events of medium intensity.
- Structures might sustain damage but should not collapse during events of exceptionally severe intensity.

Table 1.1 lists some hospitals that have suffered serious structural damage or collapse, or had their operations curtailed due to nonstructural damage and functional problems during earthquakes; Table 1.2 provides examples of effects of earthquakes on selected facilities.

Table 1.1.
Selected hospitals affected by earthquakes

HOSPITAL	COUNTRY	EARTHQUAKE
Kern Hospital	USA	Kern County, 1952
Hospital Traumatológico	Chile	Chile, 1960
Valdivia Hospital	Chile	Chile, 1960
Elmendorf Hospital	USA	Alaska, 1964
Santa Cruz Hospital	USA	San Fernando, 1971
Olive View Hospital	USA	San Fernando, 1971
Veterans Admin. Hospital	USA	San Fernando, 1971
Social Security Hospital	Nicaragua	Managua, 1972
Escalante Padilla Hospital	Costa Rica	San Isidro, 1983
Benito Juárez Hospital	Mexico	Mexico, 1985
Medical Center	Mexico	Mexico, 1985
Benjamín Bloom Hospital	El Salvador	San Salvador, 1986
San Rafael Hospital	Costa Rica	Piedras Negras, 1990
Tony Facio Hospital	Costa Rica	Limón, 1991
Olive View Hospital	USA	Northridge, 1994
Municipal Hospital	Japan	Kobe, 1995
Antofagasta Hospital	Chile	Antofagasta, 1995
Tena Hospital	Ecuador	Ecuador, 1995
Coquimbo Hospital	Chile	Chile, 1997
Antonio P. de Alcalá Hospital	Venezuela	Cumaná, 1997
Miguel H. Alcívar Hospital	Ecuador	Bahía Caráquez, 1998

O.D.Cardona

Photograph 1. Total collapse of the Benito Juárez Hospital, Mexico City, 1985.

J. Grases

Photograph 2. Partial collapse of the Benjamín Bloom Hospital, San Salvador, 1987.


O.D.Cardona

Photograph 3. Collapse of the fifth floor of the Municipal Hospital, Kobe, 1995.

Table 1.2.
General effects of earthquakes on selected hospitals

Earthquake	Magnitude (Richter Scale)	General Effects
San Fernando, California, U.S.A., 1971	6.4	Three hospitals suffered severe damage and were unable to operate normally when they were needed most.Furthermore, most of the earthquake victims went to two of the collapsed hospitals.Olive View Hospital, one of the most severely affected hospitals, was retrofitted.
Managua, Nicaragua,1972	5.6	The General Hospital suffered severe damage. It was evacuated and later demolished.
Guatemala City, Guatemala, 1976	7.5	Several hospitals were evacuated.
Popayán, Colombia, 1983	5.5	San Jose University Hospital suffered damage and service was interrupted.

Earthquake	Magnitude (Richter Scale)	General Effects
Mendoza, Argentina, 1985	6.2	More than 10% of all hospital beds were lost (state + private = 3,350). Of the 10 facilities affected, 2 were demolished and 1 evacuated.
Mexico City, Mexico, 1985	8.1	Five hospitals collapsed and 22 more suffered serious damage. At least 11 facilities were evacuated. Direct losses were estimated at US$ 640 million. The most seriously damaged hospitals were the National Medical Center of the Mexican Social Security Institute (IMSS), the General Hospital and the Benito Juárez Hospital. Between destroyed and evacuated hospitals, the earthquake produced a sudden deficit of 5,829 beds. A total of 295 lives were lost at the General Hospital and 561 at Juárez Hospital, including patients, doctors, nurses, administrative personnel, visitors and newborns.
San Salvador, El Salvador, 1986	5.4	More than 2,000 beds were lost, with more than 11 hospitals affected. Ten hospitals were evacuated and one completely destroyed. Damage was estimated at US$ 97 million.
Tena, Ecuador, 1995	6.2	Velasco Ibarra Hospital (120 beds) suffered moderate nonstructural damage: cracked walls, broken windows, fallen ceilings, damage to the elevator system and some oxygen and water conduits. Service was suspended and the facilities evacuated.

Natural disasters seriously damaged 93 hospitals and 538 health centers in Latin America and the Caribbean between 1981 and 1996, causing structural collapse or extensive damage that left the health facilities in vulnerable conditions requiring evacuation. Considering an average capacity of 200 beds per hospital and 10 beds per health unit, losses during this period totaled an estimated 24,000 beds. With an average regional cost of US$ 130,000 per hospital bed (the cost is approximately US$ 220,000 in the English-speaking Caribbean and US$100,000 in Latin America), direct accumulated losses in the region are estimated to be US$3.12 billion dollars.[2]

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[2] Economic Commission for Latin America and the Caribbean (ECLAC). Impactos económicos de los desastres naturales en la infraestructura de salud. Report no. LC/MEX/L.291. Mexico City, January 1996.

Hospitals and disaster situations

For the most part, health services are provided by a variety of health care establishments such as hospitals, health centers, health posts, and clinics. They may be managed by the government or the private sector. Hospitals normally offer emergency services and secondary or tertiary medical care, while health posts offer primary care and some first aid or basic care.

With their specific focus on treating sickness and injury, health care establishments clearly play a critical role in disaster response. As a result, special considerations for risk prevention and mitigation must be made from the moment of a hospital's conception. Two factors make this special approach fundamental to health care establishments:

a) Their complexity and occupancy characteristics;
b) Their role in the preservation of life and health in disaster situations, especially in diagnosing and treating sickness and injury.

Complexity and occupancy: causes of vulnerability

Hospitals are essential to disaster response, but they also tend to be highly vulnerable because of the following characteristics:

Complexity. A hospital is a highly complex facility which, by providing health care, must also function in certain ways as a hotel, an office building, a laboratory and a warehouse. The hotel aspect alone is complex, involving food and beverages as well as lodging. Health facilities generally include many small

R. Boroschek

Photograph 4.The lives of some occupants depends on equipment and uninterrupted supply of electricity and gases.

rooms and long corridors. Patients and visitors will be very confused in the wake of a disaster, when there may not be electrical power and fallen furniture or rubble may block corridors and room exits. Elevators will be out of service and stairways may be difficult to use.

Occupancy. Hospitals have a high level of occupancy, with patients, medical and support staff, and visitors present 24 hours a day. Many patients require assistance and continual specialized care. They may be surrounded by medical equipment, use potentially dangerous gases, or be connected to life-support equipment that requires an uninterrupted power supply.

Critical supplies. Most of the supplies required by hospitals (medicine, splints, bandages, etc.) are essential to patients' survival and crucial to the treatment of disaster victims.

Basic facilities. No facility depends on public services or lifelines more than a hospital, which cannot function without power, water, clinical gases, oxygen, fuel, garbage collection or communications.

Hazardous materials. Many products found in hospitals are dangerous if they spill or leak. The collapse of shelves holding medicines or chemicals can release poisonous liquid or gas. Spilled chemicals, damaged gas cylinders and ruptured oxygen lines can cause fires. The absence of normal security measures can also lead to the abuse of drugs normally kept under lock and key.

Heavy objects. Medical equipment and other appliances are often located above or near patients' beds or on high shelves. During a disaster, such equipment may fall, causing serious injury or obstructing evacuation routes. Other pieces of specialized equipment, such as X-ray machines, backup generators or autoclaves, are extremely heavy and may be tossed about or overturned during an earthquake.

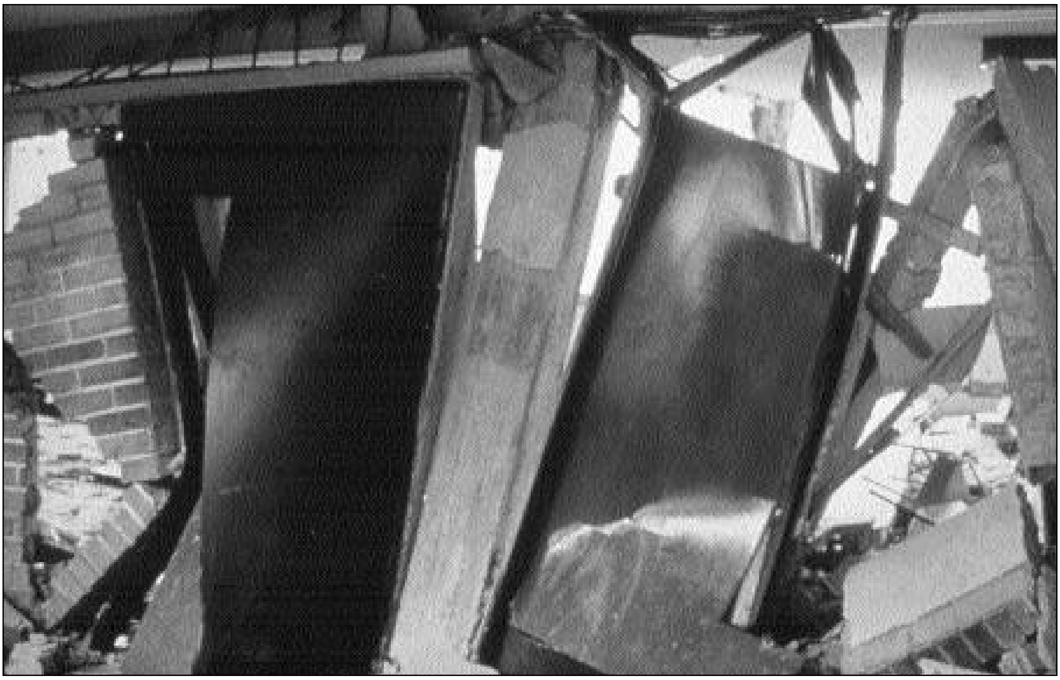
To summarize, a hospital is a complex system that demands uninterrupted power and potable water, continual communications services, solid and liquid waste disposal, and a steady supply of pharmaceutical products, medical and surgical supplies, specialized gases, chemicals and fuels. At the same time, each of these necessities also represents a hazard if improperly stored, handled, or maintained, and can become a hazard during an earthquake, fire, explosion or other disaster.

The hospital in disaster situations

As outlined above, at any given moment, a hospital may have a high population of resident patients, outpatients, medical and paramedical staff, administrative employees, and visitors. As a result, there are three main elements to disaster preparedness planning:

1. Treatment of patients must continue during and after a disaster or emergency.
2. The safety of all occupants must be assured. A vulnerability assessment of the facilities should be conducted. If necessary, the building should be retrofitted according to current design and construction standards. If this is not immediately possible, emergency plans should be adapted in the meantime to take the existing vulnerability factors into account.

3. At some point during an emergency or disaster, it may be necessary to evacuate ambulatory and non-ambulatory patients. This will be more complex if the disaster occurs suddenly and at a time when there are many visitors who are generally unfamiliar with evacuation procedures. Throughout Latin America, the number of visitors at peak hours, such as weekends, can be as high as double the number of patients.



O.D.Cardona

Photograph 5. Column failure during earthquake.

A hospital's capacity for effective disaster response depends on systematic organization and easy mobilization of personnel, equipment and supplies in a safe environment. Procedures, buildings and equipment are all critical and interdependent. A weakness in any element of a hospital's functional system could cause a crisis throughout the institution. The following issues must be taken into consideration:

Emergency procedures. Emergency procedures are especially important in the mobilization of people, equipment and supplies. The design of the necessary procedures includes the formation of a committee to formulate and implement disaster mitigation measures and carry out emergency response planning.

Buildings. Disaster mitigation plans must address the need for repairs in case of damage to the hospital facilities, both before and after a disaster occurs. Past events have demonstrated that existing plans are deficient in this area. The design and construction of hospital buildings must take into account occupants' safety and the preservation of critical areas including the emergency room, diagnostic services, surgery units, pharmacy, and food and medicine storage areas.

In the past, hospital design emphasized optimum use of space and configuration of services so as to provide the most effective interrelation of functions and activities among different departments. Many new hospitals built with modern design and construction techniques have been found lacking when called upon to attend to massive numbers of injured patients. This is often due to defects in the distribution of elements and the location and arrangement of nonstructural components. Many establishments fail due to simple design omissions that could have been corrected at a marginal cost during construction or through later intervention.

O.D.Cardona

Photograph 6. Collapse of stairway during earthquake prevents evacuation.

Equipment. The items found within a hospital building are more likely to become a hazard during an earthquake than during a hurricane. A great deal of damage can be averted through simple, inexpensive mitigation measures, such as securing shelves to the walls and placing equipment strategically in safe locations. Regular inspections and appropriate maintenance can assure that equipment is kept in good working order.

Estimating damage to hospitals after a disaster

The assessment of damage sustained by a hospital should be conducted by a multidisciplinary team including doctors, engineers and architects. The team should develop a strategy that will allow hospital activities to continue effectively despite the upheaval caused by the disaster. The assessment strategy will depend on the kind of disaster. In the case of an earthquake that has caused the partial or total collapse of the physical structure, files on the building’s infrastructure, service capacity and the number of people occupying it when the disaster occurred may be destroyed so it may be necessary to gather this information from outside sources.

The assessment process should begin with a precise definition of the type of installation that has been damaged. The level of complexity of the services the facility provided will influence the strategy for compiling data on the type and magnitude of damages.

An estimate of economic loss reflects the value of the assets destroyed at the time of the disaster. Their replacement will be influenced by factors such as the characteristics of the hospitals to be rebuilt, the resources available to the community or country, the level of institutional development in the health sector, the government's priorities for disaster response, and the allotment of budgetary resources. Replacement value is estimated based on the cost of new equipment, which often implies a technological improvement in the facilities. In the case of repairs, assessment is based on the market price of the inventoried assets.

In addition to direct losses from structural destruction, the estimate should include indirect losses, such as the reduced volume of services provided and the cost of attending to disaster victims in provisional facilities or transferring them to other institutions during the reconstruction process.

Although there is a wide range of indirect damages, some especially common types include:

1. Increased risk of transmission of infectious or contagious diseases and other health risks;
2. Increased cost of public and private health care, outpatient care and hospitalization;
3. Reduced standard of living for communities affected by environmental degradation such as the lack or reduced availability of potable water.

A common characteristic of natural disasters is their extreme impact on social resources, especially general services for economically disadvantaged populations. Damage to hospital establishments can accentuate the weaknesses of a national health care system, affecting or delaying the delivery of basic health care to the population.

Risk reduction in hospitals

Health authorities in Latin America and the Caribbean have worked to promote a process of institutional change, seeking to improve the allocation and use of resources and positively influence public health. Their work in hospital management has made inroads toward infrastructure development that reflects the needs of communities. Aspects of this development that relate to reducing the level of risk posed by natural disasters include:

a) Analysis of the demand for hospitals; and
b) Assessment and reduction of vulnerability.

Analysis of the demand for hospitals

Increased demand for health care and the limited supply of services have led to a resource rationalization process that has resulted in the development of planning, organizational and structural concepts such as the following:

1. The hospital network, defined as a system of health facilities that provide different levels of care, where interactions among the facilities are based on the provision of complementary services;
2. The need to prevent the disorganized growth that occurs when a hospital seeks to increase its capacity by expanding and equipping its physical plant without considering limitations such as the supply of basic materials, traffic routes, and hospital vulnerability;
3. Hospital certification or accreditation by level of care which constitutes an essential tool in the creation of a hospital network, and addresses criteria such as the characteristics of the popula-

tion served by the hospital, coverage areas, morbidity, type of services offered, available human resources, hospital safety, and hospital maintenance;

4. Referral and counter-referral systems comprising the standards, protocols and procedures that regulate the treatment and referral of patients from one level of health services to another. Referral systems should maximize the use of resources on the basis of efficiency, effectiveness and opportune health care.

The potential for an increase in the demand for health services after a natural or anthropic disaster requires that changes be made in the way the system functions. To be effective, these changes must take into account the type of event, as well as its magnitude, intensity and duration, and the place, population and infrastructure affected by it. It is also important to take into account epidemiological data, morbidity and mortality rates, and the general state of public health in the region. This information must be applied to aspects of the health system's ability to provide services in order to develop an optimal supply/demand ratio in the event of a disaster. An assessment of the potential demand for health services is important in order to identify variables that can have a negative influence and address them before disaster strikes.

Assessing and reducing vulnerability

Given the importance of an efficient response to emergencies and the need for a functional health care infrastructure in the aftermath of a disaster, hospital administrators must conduct structural, nonstructural and administrative/organizational vulnerability studies. Hospital vulnerability can only be determined through an integrated vulnerability assessment covering all three of these factors.

> Some of the results of a structural vulnerability assessment will serve as raw data for the assessment of nonstructural vulnerability. Nonstructural assessment, in turn, plays a key role in determining administrative/organizational vulnerability. An integrated hospital vulnerability assessment should address all three elements in the following order: (a) structural vulnerability, (b) nonstructural vulnerability, and (c) administrative/organizational vulnerability.

A vulnerability assessment may begin with a visual inspection of the facilities and a preliminary report by a team of experts that identifies areas in need of attention. The report may be discussed with other consultants and the hospital administration in order to set priorities and time frames for making the necessary changes.

Structural vulnerability

The terms "structural" or "structural components" refer to those parts of a building that are required for physical support. They include foundations, columns, supporting walls, beams and diaphragms (i.e., floors and ceilings designed to transmit horizontal forces occurring in an earthquake through beams and columns into the foundation).

Both existing and planned health care establishments in areas exposed to seismic activity must comply with building codes for seismic resistance. These codes are intended to ensure the safety of the building's occupants and, secondarily, to allow the facility to continue functioning during and after the event. Although completely earthquake-proof structures are financially unrealistic, seismic-resistance standards provide design criteria to avert collapse and assure functionality after an earthquake.

Nonstructural vulnerability

The term "nonstructural" refers to components that are physically joined to a building's structure (including partitions, windows, roofs, doors, and ceilings), those that are essential to the building's functionality (such as plumbing, heating, air conditioning, and electrical connections), and items located within the building (such as medical or mechanical equipment, or furniture). The three categories of nonstructural elements are therefore architectural components, installations, and equipment. In the case of health care facilities, nonstructural components often represent a greater economic value than the structure itself. Analyses indicate that nonstructural components generally account for more than 80% of the total cost of a hospital.

In some situations, nonstructural components can affect the occurrence of a structural failure. Heavy equipment such as central air-conditioning systems, X-ray equipment, CT scanners, electrical generators, boilers and hydrotherapy pools may be found on the upper stories of a hospital or on a floor dedicated to these central systems. The placement of this equipment can significantly modify the original calculations of a structure's behavior. Unanchored equipment may also slide or roll, causing a partial or total structural collapse. Architectural elements such as unreinforced stucco and heavy facades can also alter the behavior of the building as it vibrates.

In terms of the hospital's functionality, the damage or loss of some nonstructural elements can seriously disrupt the provision of services. While they do not represent a direct danger to building occupants, such losses pose an indirect risk through the failure of equipment or systems. For example, damage to an electrical generator may interrupt the power supply to basic life-support systems, such as the respirators in an intensive care unit.

Administrative/organizational vulnerability

The term "administrative or organizational vulnerability" refers primarily to the distribution of space, and the relationships between these spaces and the medical or health care services provided in the hospital. It also refers to the physical and functional relationships between the different areas, and to administrative processes such as hiring, supply procurement, maintenance routines, and so on. Appropriate zoning and relationships between the areas of a facility can assure adequate functioning not only under normal conditions, but also in case of emergency or disaster. The arrangement and relationship between outpatient consultation areas, areas surrounding the structure, and emergency services, and the creation of a specially protected area for general support services, can ensure appropriate medical treatment and avoid the functional collapse that can occur even if the building has not suffered severe damage.

It is the health care administrator's responsibility to anticipate and address these issues in order to reduce the potential loss of service and the social impact that occurs when efficient health care cannot be provided when it is most needed, after a disaster.

Planning and financing

Health care administrators should seek opportunities to incorporate disaster prevention and mitigation concepts into processes such as maintenance, expansion projects, equipment upkeep and hospital accreditation. Coordination with government and private institutions that study geological, seismological and hydrometeorological conditions will assist in the identification of the different types of hazards facing existing or future health care facilities. This information allows appropriate prevention and mitigation measures to be taken, reducing the hospital infrastructure's overall vulnerability. Administrators should use vulnerability assessments to reach a realistic balance between the required investment and the expected benefit in terms of mitigation of economic and social losses. An acceptable level of risk will be defined and ultimately reached through the application of the appropriate measures.

Hospitals should carry out ongoing risk mitigation planning based on the information described above, within the framework of an institutional policy that formulates the necessary objectives, strategies and activities. Preparations for emergency response are interdependent and complementary to risk mitigation activities.

Promotion and financing strategies

One of the difficulties in implementing disaster mitigation strategies is demonstrating the need for such investment: that is, its cost effectiveness. Factors that can weigh against the investment include the difficulty of predicting certain types of natural events, and the near-permanent economic crises faced by health care facilities in most developing countries. However, a convincing argument can still be made that reducing the vulnerability of health services, in order to guarantee the safety of people, equipment and services when they are most needed, is a highly cost-effective decision in both social and economic terms.

Promotion and financing can take a variety of forms. The approaches listed below are easy to implement, although they obviously require the previous or simultaneous development of a disaster mitigation program for health care establishments. Such a program should include human resource development and training, technological development, the establishment of standards and regulations, and the provision of expert knowledge by consultants.

- *Approval of operating licenses*. The approval or renewal of health care facilities' operating licenses provides an excellent opportunity to require all centers to adopt seismic-resistant construction techniques and take measures for disaster preparedness and mitigation.
- *Approval of investment budgets*. Budgetary line-items represent one of the most common means of promoting specifically focused investments and development processes. This tool can also be used to ensure that institutional development plans include disaster mitigation and preparedness measures. Financing for maintenance or construction projects, such as remodeling or expansion, can be made contingent on the execution of a vulnerability assessment and the inclusion of mitigation measures in the design. As mentioned earlier, it is considerably more cost-effective to build a seismically resistant health care center or retrofit an existing structure than to cope with the economic and social losses from the structural collapse of a hospital, with its consequent morbidity, mortality, loss of equipment and interruption of health care services.
- *Hospital accreditation processes*. The concept of accreditation, which became popular several years ago, involves a centralized entity that stipulates the conditions under which health care can be provided (see box 1.1). Individual institutions are required to fill in standardized forms for the assessment of criteria that can range from the condition of the physical plant to the equipment used and the quality of human resources. The accrediting body reviews the forms and issues a qualification to the institution. The accreditation must be renewed periodically, and can hinge on specific disaster mitigation and preparedness measures.
- *Approval of incentive-oriented budget items*. Economic support is another way to promote mitigation and preparedness measures in hospitals. Incentives can include co-financing for vulnerability studies, consulting or design work, or execution of some of the necessary modifications.

A hospital prepared for disaster situations: The "SAFE HOSPITAL"[3]

The Mexican Social Security Institute (IMSS) has presented an initiative designed to assure that hospitals are safe and prepared for disaster response. The plan has four stages:

1. A vulnerability assessment is conducted in hospitals that provide secondary and tertiary levels of care (i.e., the most complex hospitals). The personnel of each hospital carries out this analysis on the basis of the environmental hazards present. The results of the analyses are used in developing or updating Disaster Health Care Plans (PAISD) appropriate to the vulnerabilities of each establishment. Simple, low-cost corrective measures are implemented to address the problems detected.
2. An Institutional Certification Committee made up of specialized professionals performs an exhaustive vulnerability assessment of any secondary or tertiary level institution that requires such an assessment. The relevant mitigation measures are implemented, and the PAISD revised, according to current standards.
3. A competent national body validates the results obtained in steps 1 and 2.
4. International recognition as a "Safe Hospital" is granted to those establishments that meet the parameters established by the national body mentioned in step 3.

International participation

Risk reduction in hospitals and health care establishments has been consistently promoted in Latin America and the Caribbean in recent years due to the need to raise safety levels in the health care infrastructure in the region. The Pan American Health Organization (PAHO/WHO) has worked to attain the political commitment by health care authorities, encouraged regional exchange of expertise and experience in this area, and has promoted dissemination of information and technical training for the professionals involved, encouraging a multidisciplinary approach. This book, for example, is the result of activities designed to promote risk mitigation in health care establishments.

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[3] The full description of this project can be found in the report *Hospital preparado para enfrentar situaciones de desastre: "Hospital Seguro,"* prepared by the Mexican Social Security Institute in September 1998.

International Conference on Disaster Mitigation in Health Facilities[4]

In 1996, the Pan American Health Organization, under the auspices of the Government of Mexico and with the support of the Secretariat of the International Decade for Natural Disaster Reduction (IDNDR), the Department of Humanitarian Affairs (DHA) of the United Nations, the Economic Commission for Latin America and the Caribbean (ECLAC), the Organization of American States (OAS), and the World Bank, convened an International Conference on Disaster Mitigation in Health Facilities.

For the first time, health care authorities from throughout the Region made commitments for the 1996-2001 period to reduce the impact of natural disasters in high-priority health care facilities. Priority status was based on vulnerability and each country's political, economic and logistical capacity. Some of the most important commitments for immediate fulfillment included:

- To formally determine which existing health care institutions have priority for vulnerability studies and disaster impact reduction measures;
- To introduce mitigation measures in the design and construction of new health care facilities and in remodeling and expansion of existing facilities;
- To include nonstructural disaster mitigation or intervention measures in all maintenance, inspection, restructuring and improvement of existing hospitals;
- To identify budgetary resources and have hospital disaster mitigation plans classified as a priority.

Several countries in the Region have developed projects to partially or fully comply with the Conference recommendations.

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[4] Pan American Health Organization. Subcommittee on Planning and Programming of the Executive Committee, 30th session, 30 and 31 March 1998. SPP30/6, Rev. 1, Washington D.C., 29 April 1998.

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Chapter 2
Structural Vulnerability

Background

Structural vulnerability refers to the susceptibility of those parts of a building that are required for physical support when subjected to an intense earthquake or other hazard. This includes foundations, columns, supporting walls, beams, and floor slabs.

Strategies for implementing disaster mitigation measures in hospital facilities will depend on whether the facilities already exist or are yet to be constructed. The structural components are considered during the design and construction phase when dealing with a new building, or during the repair, remodeling, or maintenance phase of an existing structure.

Unfortunately, in many Latin American countries, earthquake-resistant construction standards have not been effectively applied, and special guidelines have not been considered for hospital facilities. For this reason, it is not surprising that each time an earthquake occurs in the region, hospitals figure among the buildings most affected, when they should be the last to suffer damage. The structural vulnerability of hospitals is high, a situation that must be totally or partially corrected in order to avoid enormous economic and social losses, especially in developing countries.

Since many hospital facilities are old, and others have neither been designed nor built to seismic-resistant standards, there are doubts as to the likelihood of these buildings continuing to function after an earthquake. It is imperative to use vulnerability assessments to examine the ability of these structures to withstand moderate to strong earthquakes.

Structural damage

Experience of seismic activity in the past shows that in countries where design meets good seismic-resistant standards, where construction is strictly supervised, and where the design earthquake is representative of the real seismic risk to the area, damage to infrastructure is marginal in comparison to that observed in locations where such conditions are not met.

Adherence to a seismic building code when designing a hospital does not necessarily safeguard against the damage produced by severe earthquakes.Seismic standards establish minimum requirements to protect the lives of occupants, requirements that many times are not sufficient to guarantee that a hospital will be able to function after an earthquake.

From a historical perspective, a code by itself cannot guarantee safety from excessive damage, since codes are rules that establish minimum requirements, which are continually updated in accordance with technological advances and lessons learned through research and study of the effects of earthquakes. Ductility (i.e., energy absorption capacity) and structural redundancy have proven to be the most effective means of providing safety against collapse, especially if the movements are more severe than those anticipated by the original design. Severe damage or collapse of many structures during major earthquakes is, in general, a direct consequence of the failure of a single element or series of elements with insufficient ductility or strength.

Structural damages as a result of strong earthquakes are frequently found in columns, including diagonal cracks caused by shearing or twisting, vertical cracks, detachment of column sheathing, failure of concrete, and warping of longitudinal reinforcement bars by excessive flexocompression. In beams, diagonal cracks and breakage of supports due to shearing or twisting are often seen, as are vertical cracks, breakage of longitudinal reinforcements, and failure of concrete caused by the earthquake flexing the section up and down as a result of alternating stresses

The connections or unions between structural elements are, in general, the most critical points. In beam-column connections (ends), shearing produces diagonal cracks, and it is common to see failure in the adherence and anchorage of the longitudinal reinforcements of the beams because of their poor design or as a consequence of excessive flexural stress.

In the slabs, cracks may result from punctures around the columns, and longitudinal cracks along the plate due to the excessive flexure that earthquakes can cause in certain circumstances. This type of damage has been seen repeatedly in hospital facilities submitted to moderate to strong seismic movements.

Observations in recent years indicate that, in general, stiff construction performs better than flexible construction.This pertains particularly to nonstructural components which suffer less damage because of limited displacement between floors.

Irregularities in height, translated into sudden changes in stiffness between adjacent floors, concentrate the absorption and dissipation of energy during an earthquake on the flexible floors where the structural elements are overburdened. Irregularities in mass, stiffness, and strength of floors can cause torsional vibrations, concentrating forces that are difficult to evaluate. For this reason, a higher standard for these elements must guide the architects entrusted with the design of these buildings.

Few buildings are designed to withstand severe earthquakes in the elastic range, so it is necessary to provide the structure with the ability to dissipate energy through stiffness and ductility, in the places where it is expected that elastic strength may be exceeded. This is applied to structural elements and connections between these elements, which are usually the weakest points.

Recommended safety levels

The 33rd Report of the Applied Technology Council (ATC-33)[1] defines several levels of safety for a building in case of an important seismic event. Table 2.1 presents recommendations for the so-called "Vision 2000" requirements.

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[1] Applied Technology Council (ATC), *Guidelines for seismic rehabilitation of buildings* (Report 33-03). 3 Volumes. Redwood City, 1995. NEHRP guidelines for seismic rehabilitation of buildings (FEMA 273).

Table 2.1.
Vision 2000 recommended objectives of seismic performance

Seismic Level	**Required performance level**			
	Fully functional	Operational	Life safety	Near collapse
Frequent (50%/30 years)	×		**Unacceptable performance** (For new buildings)	
Occasional (50%/50 years)	◆	×		
Rare (10%/50 years)	■	◆	×	
Very rare (10%/100 years)		■	◆	×

■ = Critical installation, such as hospitals, fire departments.
◆ = Essential or dangerous installation, such as a telephone center, building with toxic chemicals.
× = Basic or conventional installation, such as office and residential buildings.

In accordance with this table, a hospital must be designed in such a way that it may continue to function after a "rare" earthquake (10% probability of occurrence in 50 years), and that it remain in conditions allowing immediate occupation after a very rare earthquake (10% probability of occurrence in 100 years). Criteria for required performance for these safety levels are outlined below.

Fully functional: In this case, the building remains in a suitable condition for normal use, although perhaps with some limitations. All of the supply systems and basic services must continue to operate. To comply with this level, it is necessary to have redundant systems or emergency equipment. A rigorous inspection of the electrical and mechanical systems is required to guarantee that they function correctly after having been strongly shaken.

Operational: In this case, only very limited damages to the structure and to the nonstructural components are seen. Systems resistant to lateral and vertical loads retain almost all of the capacity that they had before the event. Nonstructural damage is minimal, so that access routes and safety systems (such as doors, stairs, elevators, emergency lights, fire alarms, etc.) remain operational, assuming that a power supply is available. Broken windows and slight damage to connections or lights may occur. It is expected that the occupants could remain in the building, although normal use of the establishment could be limited, and cleaning and inspection become necessary. In general, electromechanical components are secure and should operate if required. Calibrations in some equipment could be lost and misalignments or other damage could render them useless. There could be a loss of power and water, and problems with communication lines and gas pipes. While the risk of severe injury is low and the building may be occupied at this design level, it is possible that repairs will have to be made before normal function can resume.

Life safety: At this level significant damage to the structure is present, although a certain degree of protection against total or partial collapse is expected. Damage is greater than in the previous case. The majority of structural and nonstructural components have not failed, and do not constitute a threat inside or outside of the building. Evacuation routes remain operational, but may be limited by accumulations of rubble. Injuries may arise during the earthquake, but they are not expected to be life-threatening. It is possible to repair the structure, although in some cases this may not be practical from an economic point of view.

Near collapse: Damage after the earthquake is such that the building may suffer a partial or total collapse as a consequence of the degradation of the rigidity or the strength of the support system to lateral stresses, the permanent lateral deformation of the structure, or the reduction of its ability to support vertical loads. All of the basic components of the system that are resistant to gravitational loads may continue functioning. While the building may maintain its stability, a serious risk exists for injuries due to falling objects. It is unlikely that it will be practical to retrofit the structure, and the building is not safe for immediate occupation, since aftershocks could cause collapse.

The objective of the seismic-resistant design process is to ensure that the facility will be fully functional, regardless of the severity of the earthquake. It is not possible to carry out an effective assessment of nonstructural and administrative-organizational vulnerability (covered in chapters 3 and 4 of this book) if structural vulnerability has not been assessed. However, the importance of taking measures to mitigate nonstructural and administrative-organizational vulnerability cannot be overemphasized, since these aspects are as susceptible to damage from small to moderate seismic events, which occur more frequently, as they are to earthquakes that can affect structural components.

Assessing the condition of an existing building can raise serious doubts about its ability to withstand seismic events. In some countries, retrofitting campaigns for existing buildings have been launched in order to reduce vulnerability (see boxes 2.1–2.5 for examples of national initiatives). In principle, one would think that retrofitting would be obligatory for essential buildings identified as being structurally vulnerable.

Box 2.1.Legislating hospital assessment in Colombia

The Colombian Seismic-Resistant Construction and Design Standards, known as NSR-98 were signed into law in 1998 (Law 400 of 1997 and Decree-Law 33 of 1998).The law requires that essential buildings located in earthquake-prone areas be assessed as to their vulnerability within a period of three years and inspected or reinforced within a period of six years.This obliges the national,departmental and municipal governments to include budget allotments to that end in the coming years and take into account this type of investment in future development plans.

The Standards define essential buildings as follows:
"Those buildings serving the community that must function during and after an earthquake, whose operation cannot be moved rapidly to an alternate location,such as hospitals with complexity levels of 2 and 3,as well as centers responsible for lifeline operation and control."

Article 54 of the law stipulates that:
"Existing buildings whose use classifies them as essential structures,located in areas of intermediate to high seismic threat, must be assessed for their seismic vulnerability in accordance with the procedures established in these regulations within a period of three years from the date this law goes into effect.

"These buildings must be modified or retrofitted to bring them up to a seismic safety level equivalent to that of a structure newly designed and constructed in accordance with the requirements of this law and its regulations,within a period no greater than six years from the date this law goes into effect."

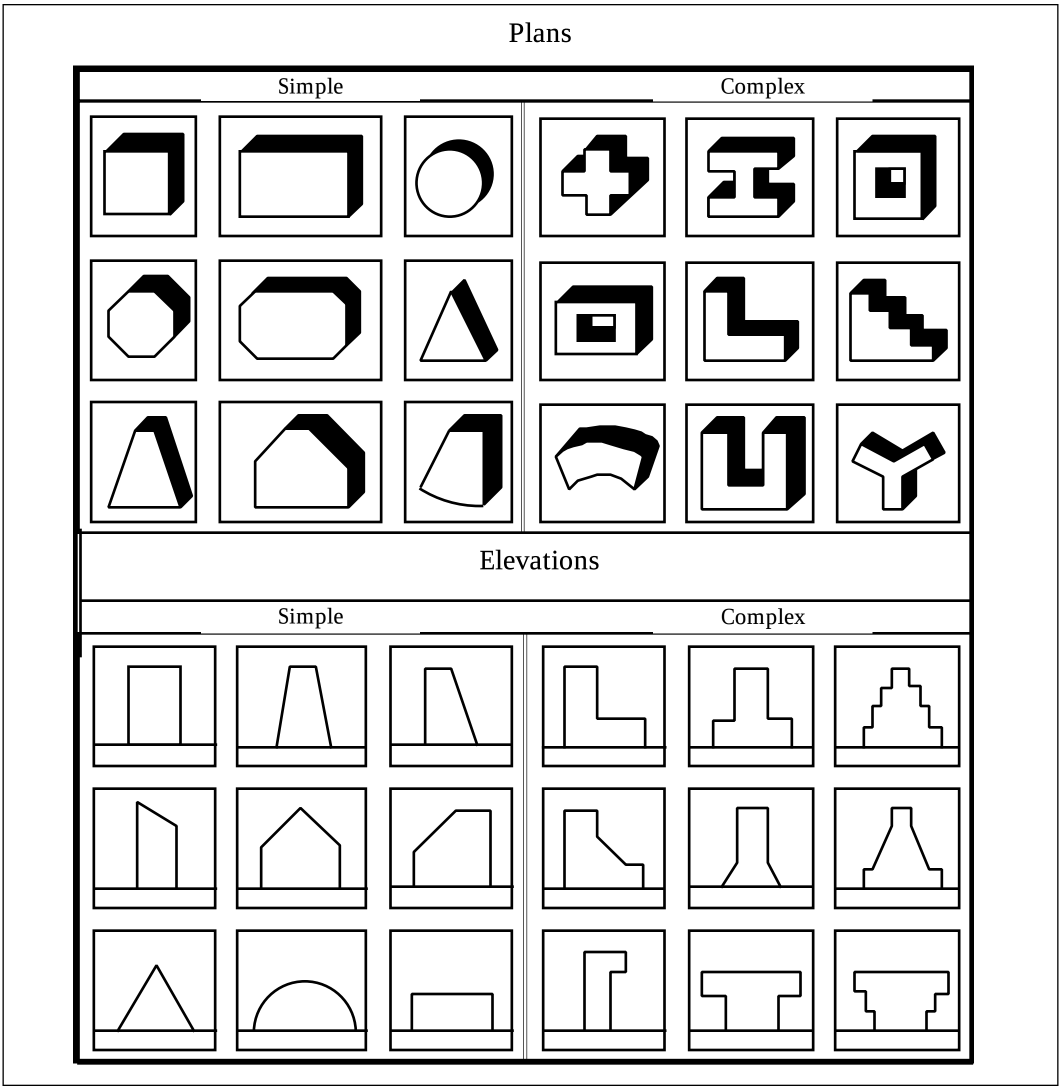
Armed with this judicial instrument,the Colombian Ministry of Health and the National Department for the Prevention and Management of Disasters will be able to strengthen their nationwide program to promote seismic vulnerability assessments of all existing hospitals and their retrofitting,where necessary.This work will provide impetus for national,departmental,and in some cases municipal efforts, through joint financing and matching funds provided by the Ministry of Health,the Social Investment Fund and the National Disaster Fund.Although not all secondary and tertiary hospital facilities in areas with an intermediate to high seismic hazard may have been retrofitted by the designated deadline, the regulations will undoubtedly help to advance the issue and stimulate political resolve among local and departmental governments,which in the case of Colombia share responsibility for the enforcement of this law. Even before the new standards were in place , efforts were underway at the local and departmental levels to design the retrofitting of several key hospitals. Once the new regulations have been publicized,more widespread efforts will likely be seen,translating into an increase in the safety of the country's health infrastructure.

Source: Cardona, O.D. *Las edificaciones hospitalarias en la nueva legislación sísmica colombiana*. Paper presented at the International Conference on Disaster Mitigation in Health Facilities,Mexico, 1996.

Architectural and structural configuration problems

By their nature, hospital facilities tend to be large and complex, which often causes their configuration to be quite complex as well. Configuration does not refer here simply to the abstract spatial arrangement of the buildings and their components, but to their type, lay-out, fragmentation, strength and geometry, from which certain problems of structural response to earthquakes are derived. One of the greatest causes of damage to buildings has been the use of improper architectural-structural configurations. Generally speaking, it may be said that a departure from simple structural forms and layouts tends to be severely punished by earthquakes. Figure 2.1 illustrates simple and complex configurations. Unfortunately, the usual methods of seismic analysis fail to adequately quantify problems related to configuration. In any case, given the erratic nature of earthquakes, as well as the possibility of their exceeding design levels, it is advisable to avoid hazardous configurations, regardless of the degree of sophistication that may be reached in the analysis of each individual case.[2]

Figure 2.1.
Simple and complex forms in plan and elevation



Source: Reprinted from Arnold, Christopher and Reitherman, Robert, ***Building configuration and seismic design*** (John Wiley and Sons, New York: 1982, p. 232).

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[2] Applied Technology Council (ATC) (Report ATC 3-06), *Tentative Provisions for Development of Seismic Regulations for Buildings.* Palo Alto, 1978. [Spanish version published by the Asociación Colombiana de Ingenieria Sísmica, Bogotá, 1979.]

Geometric configuration

The following briefly describes the most relevant aspects of the impact of geometric configuration on the seismic response of buildings, as well as the corrective measures required. Due to their complexity and their close relationship with buildings' use of space and form, configuration problems must be taken into account from the very earliest stages of architectural design. Architects and designers should have a thorough understanding of the relevant issues.[3]

Configuration problems in the plan

The problems mentioned below refer to the plan (i.e., horizontal layout) of the structure in relation to the form and distribution of architectural space.

> The configuration problems in the plan arise when the floor plans are continuous, that is, when they are not made up of discrete units.Some floor plans that at first glance seem complex, but that rely on seismic expansion joints, may not face performance problems from earthquakes.

Length

The length of a building determines its structural response in ways that are not easily determined by the usual methods of analysis. Since ground movement consists of the transmission of waves, which occurs with a velocity that depends on characteristics of the soil on which the structure stands, the excitation that takes place at one point of support of the building at one time differs from the excitation at another time, a difference that is greater to the extent that the length of the building is greater in the direction of the seismic waves. Short buildings adjust more easily to the waves than long buildings, and undergo similar excitation at all supports.

The usual correction for the problem of excessive building length is to partition the structure in blocks by the insertion of seismic expansion joints in such a way that each block can be considered a shorter building. These joints must be designed to permit adequate movement of each block without the danger of their striking or colliding with each other.

Long buildings are also more sensitive to the torsion or horizontal rotation resulting from ground movements, because the differences in the transverse and longitudinal movements of the supporting ground, on which this rotation depends, are greater.

Concentration of stress due to complex plans.

Concentration of stress arises in buildings with complex floor plans, and is very common in hospital buildings. A complex plan is defined as that in which the line joining any two sufficiently distant points lies largely outside of the plan. This occurs when wings of significant size are oriented in different directions, for instance in H, U, or L shapes (see figure 2.2 and photograph 7).

In irregularly shaped floor plans, the wings may be likened to a cantilever built into the remaining

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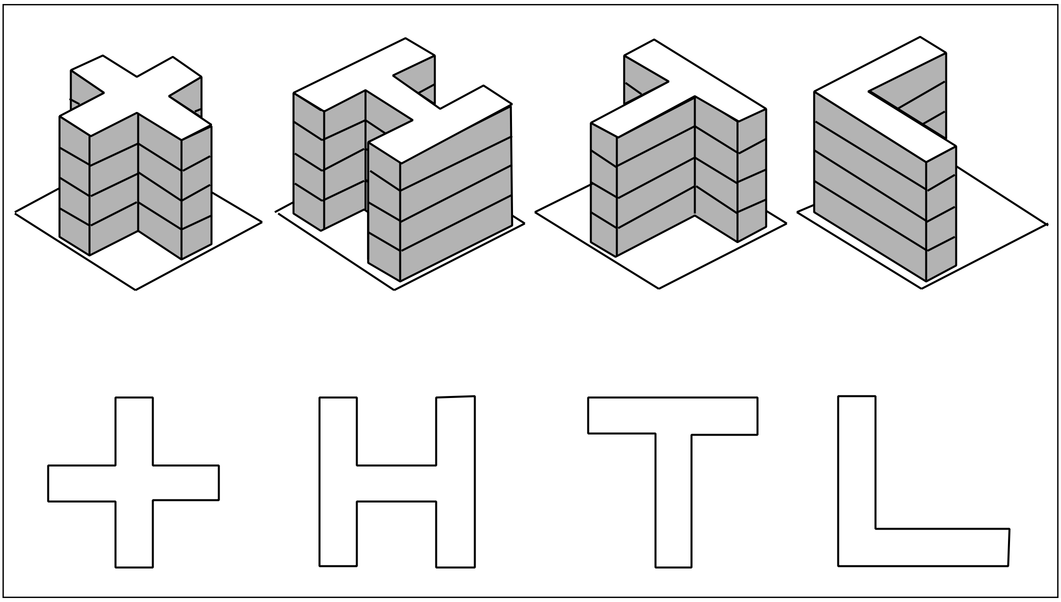
[3] Bazán, E., Meli, R., ***Manual de diseño sísmico de edificios***, Mexico, D.F.,: Limusa, 1987

body of the building, a point that would suffer smaller lateral distortions than in the rest of the wing. Large concentrations of stress appear in such transition areas, frequently producing damage to the non-structural elements, the vertical structure, and even the diaphragms (that is, the horizontal resistant elements of a structure such as floors and roofs).

Figure 2.2.
Complex plans



T. Guevara

O.D.Cardona

Photograph 7. Caldas Hospital in Colombia

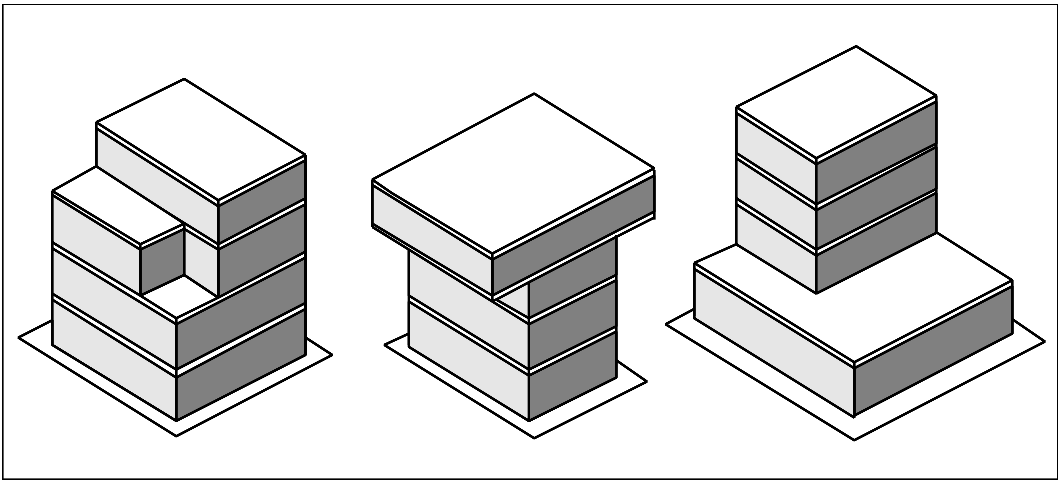
In such a case, the solution currently used is to introduce seismic expansion joints like those mentioned in the case of long buildings. These joints allow each block to move without being tied to the rest of the building, which interrupts the cantilever effect of each wing. The joints, obviously, must be wide enough to permit the movement of each block without striking adjacent blocks.[4]

Vertical configuration problems

Setbacks

Setbacks in the volume of a building usually arise from urban design demands for illumination, proportion, etc. However, in seismic events they are the cause of abrupt changes in stiffness and mass producing a concentration of stresses in the floors near the site of sudden change (figure 2.3). In general terms, one should ensure that the transitions are as gradual as possible in order to avoid such concentration of stresses.

Figure 2.3.
Buildings with irregular vertical shape



T. Guevara

Figure 2.4 shows some characteristics of building configuration that should be avoided in health facilities, due to their inadequate performance in earthquakes.

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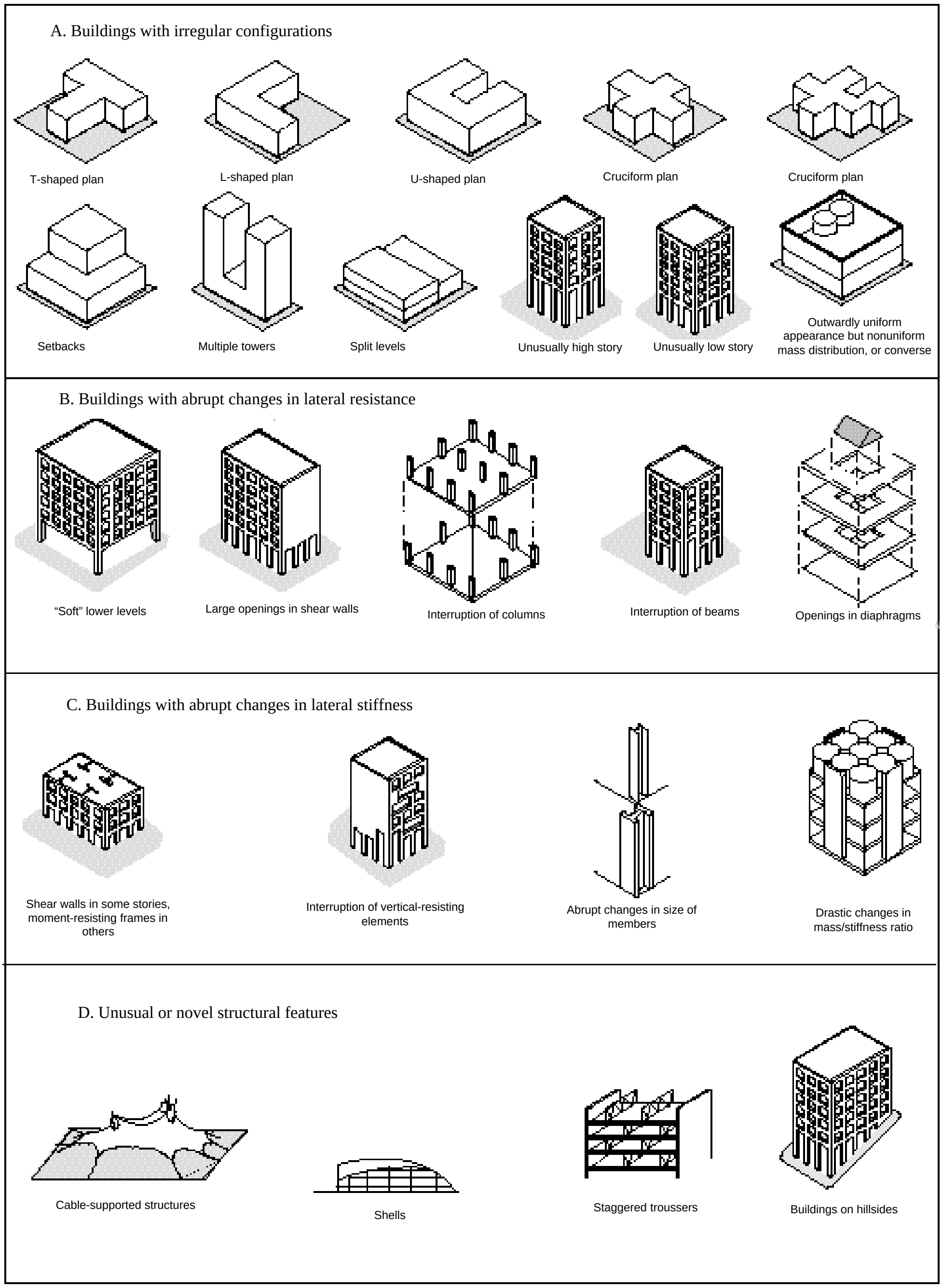
[4] Dowrick, D.J. ***Diseño de estructuras resistentes a sismos para ingenieros y arquitectos***. Mexico: Limusa, 1984.

Figure 2.4.
Irregular structures



Graphic interpretation of irregular structures or framing systems, from the Commentary to the SEAOC Recommended Lateral Stress Requirements and Commentary. Reproduced in Arnold, Christopher and Reitherman, Robert, *Building Configuration and Seismic Design* (John Wiley and Sons, New York: 1982, p. 8). Reproduced with permission.

Structural configuration

The following section describes issues related to the performance of structural elements in response to seismic events.

Concentrations of mass

High concentrations of mass on a given level of the building are problematic. This occurs on floors where heavy items are placed, such as equipment, tanks, storerooms, or filing cabinets. The problem is greater the higher the heavy level is located, due to the fact that seismic response accelerations increase upward, increasing seismic forces and the possibility of equipment collapsing and causing structural damage (see photograph 8).

PAHO/WHO

Photograph 8. Concentrations of mass, such as water tanks placed on the roof of a hospital, can cause severe damage in earthquakes.

In architectural design, it is recommended that spaces for unusually heavy weights be in basements or in buildings isolated from the main structure. If elevated water storage is required for topographical reasons, it is preferable to build independent towers instead of attaching towers to the main building.

Weak columns

Columns have vital importance as they are the elements that transmit seismic loads to the foundations and keep the structure erect. Any damage to columns can cause a redistribution of loads between the elements of the structure and cause the total or partial collapse of a building.

The use of frames (structures formed by beams and columns) in seismic design seeks to ensure that the damage from intense earthquakes is produced in beams rather than in columns, due to the greater risk of the building collapsing from damage to the columns. However, many buildings designed according to seismic-resistant codes have failed in this regard. These failures can be grouped into two classes:

- Columns with less resistance than beams.
- Short columns.

In the first case, the frame has been designed so that the resistance provided to the beams that meet at a connection is greater than that of the respective columns. When the connection is twisted by seismic movement, the columns yield before the beams.

Short columns are the cause of serious failures in buildings under seismic excitation. There are several circumstances in which the free unsupported length of the columns is drastically reduced and the result can be considered a short column, including:

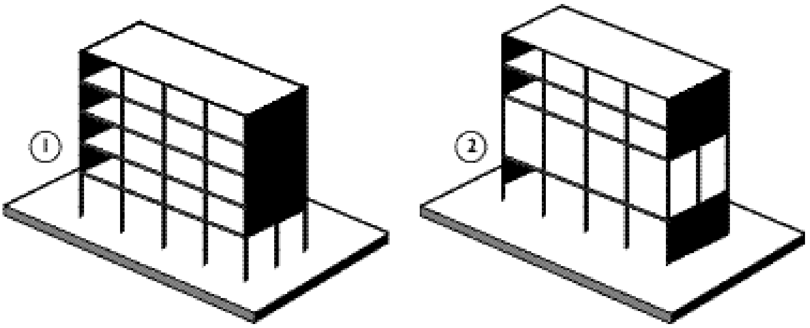
- Partial lateral confinement of the column by dividing walls, facade walls, retaining walls, etc.;
- Placement of floor slabs at intermediate levels;
- Location of the building on a slope.

Soft stories

Several types of architectural and structural plans lead to the formation of so-called "soft" stories, which are stories that are more vulnerable to seismic damage than others due to the fact that they are less stiff, less resistant, or both (see figure 2.5). The presence of soft stories can be attributed to:

- Differences in height between floors;
- Interruption of the vertical structural elements on the floor.

Figure 2.5.
Examples of buildings with "soft story" irregularity.



1. Open ground floor
2. Soft story at intermediate level

T. Guevara

Source: Guevara, Teresa. "Recomendaciones para crear diseños arquitectónicos sismo resistentes a la luz de la nueva Norma Colombiana NSR-98", Reunión del Concreto 1998, Cartagena, Colombia.

Differences in height between stories arises frequently because of the need for greater space at certain levels of the building, generally for technical (equipment requirements, etc.) or aesthetic reasons (image of the building at the access levels). This results in lessened stiffness of the stories in question, due to the greater height of the vertical elements.

The interruption of vertical elements (walls and columns) of the structure has been the cause of partial or total collapses in buildings subjected to earthquakes, especially when this occurs in the lower floors (see photographs 9–11). The level on which the elements are interrupted is more flexible than the others, which increases the problem of stability, but also because the abrupt change in stiffness causes a greater accumulation of energy on the weaker story. The most common cases of interruption of vertical elements, which occur generally for spatial, formal, or aesthetic reasons, are the following:

- Interruption of the columns
- Interruption of structural walls (shear walls)
- Interruption of partition walls (erroneously conceived as nonstructural walls) aligned with frames

O.D.Cardona

Photograph 9. Failure on ground floor due to soft story.

Lack of redundancy

Seismic-resistant structural design takes into account the possibility of damage to the structural elements by the most intense earthquakes. The design of the structure must take into account that resistance to seismic forces depends on the distribution of stress among the greatest possible number of structural elements. When there is little redundancy (i.e., a reduced number of elements) the failure of any of these can cause partial or total collapse during an earthquake.[5]

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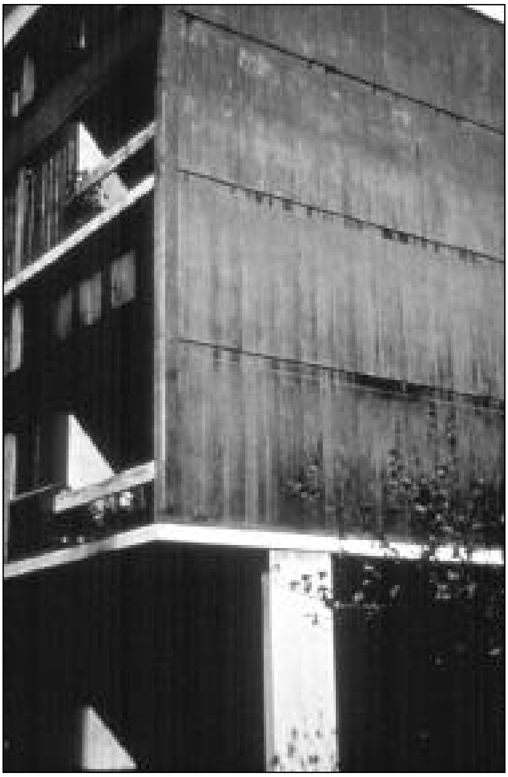
[5] PAHO/WHO, *Análisis de riesgo en el diseño de hospitales en zonas sísmicas*, Washington, D.C., 1989.



J. Grases

Photograph 10. Interruption of a structural wall on the ground floor

J. Grases

Photograph 11. Structural collapse due to the discontinuity of vertical elements.

Excessive structural flexibility

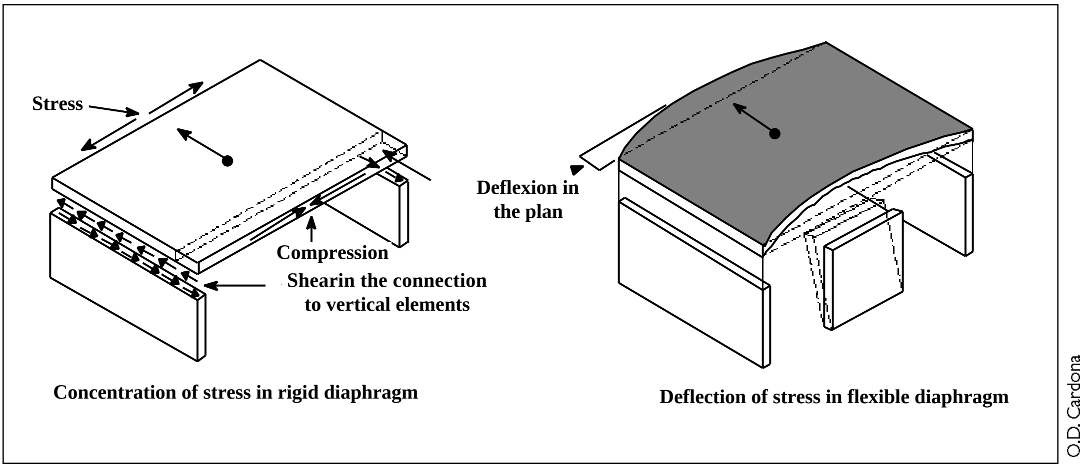
Excessive flexibility of the building to seismic loads can be defined as the susceptibility to large lateral distortions between different stories, or "drift". The main causes of this problem reside in excessive distance between the support elements (clear spaces or clearances), their vertical clearance, and their stiffness. Depending on the degree, excessive flexibility can have the following consequences:

- Damage to nonstructural elements attached to contiguous levels;
- Instability of the flexible floor or floors, or the building in general;
- Not taking advantage of available ductility.

Excessive flexibility of the diaphragm

An excessively flexible floor diaphragm involves non-uniform lateral distortions, which are in principle prejudicial to the nonstructural elements attached to the diaphragm. Additionally, the distribution of lateral forces will not be in accordance with the stiffness of the vertical elements (see figure 2.6).

Figure 2.6.
Rigid and flexible behavior of the floor diaphragm



There are several reasons why there can be this type of flexible performance. Among them are the following:

- *Flexibility of the diaphragm material.* Among the usual building materials, wood or steel decking without concrete are the most flexible.
- *Aspect ratio* (length/width) of the diaphragm. The greater the length/width ratio of the diaphragm, the greater the lateral distortions may be. In general, diaphragms with aspect ratios greater than 5 may be considered flexible.
- *Stiffness of the vertical structure.* The flexibility of the diaphragm should also be judged in accordance with the distribution of rigid vertical elements in the plan. In the extreme case of a diaphragm in which all elements are of equal stiffness, better performance is expected than when there are major differences in this respect.
- *Openings in the diaphragm.* Large openings in the diaphragm for purposes of illumination, ventilation, and visual connections between stories cause flexible areas that impede the rigid assembly of the vertical structures.

There are multiple solutions to the problem of excessive flexibility of the diaphragm, depending on its cause. Measures used to stiffen the diaphragm where large openings occur should be carefully studied; other options include segmentation of the building into blocks.

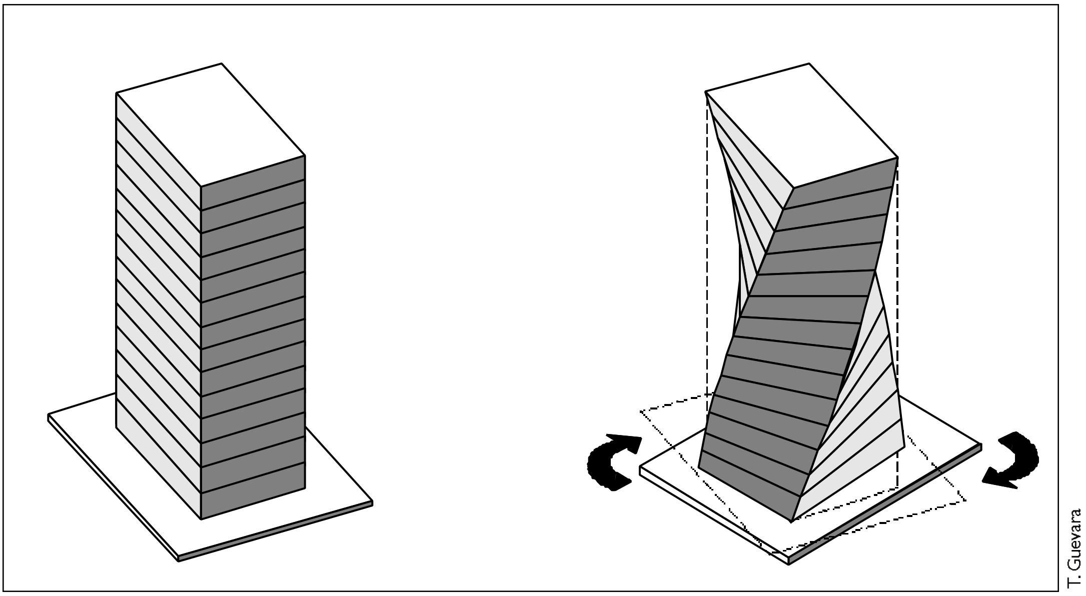
Torsion

Torsion has been the cause of major damage to buildings subjected to strong earthquakes, ranging from visible distortion of the structure (and its resultant loss of image and reliability) to structural collapse (figure 2.7). Torsion is produced by the eccentricity existing between the center of mass and the center of stiffness. Some of the situations that can give rise to this situation in the building plan are:

- Positioning the stiff elements asymmetrically with respect to the center of gravity of the story;
- The placement of large masses asymmetrically with respect to stiffness;
- A combination of the two situations described above.

It should be kept in mind that the dividing walls and the facade walls that are attached to the verti-

Figure 2.7.
Torsion



cal structure are usually very stiff and, therefore, often participate in the structural response to an earthquake and can cause torsion. This is often the case in corner buildings.

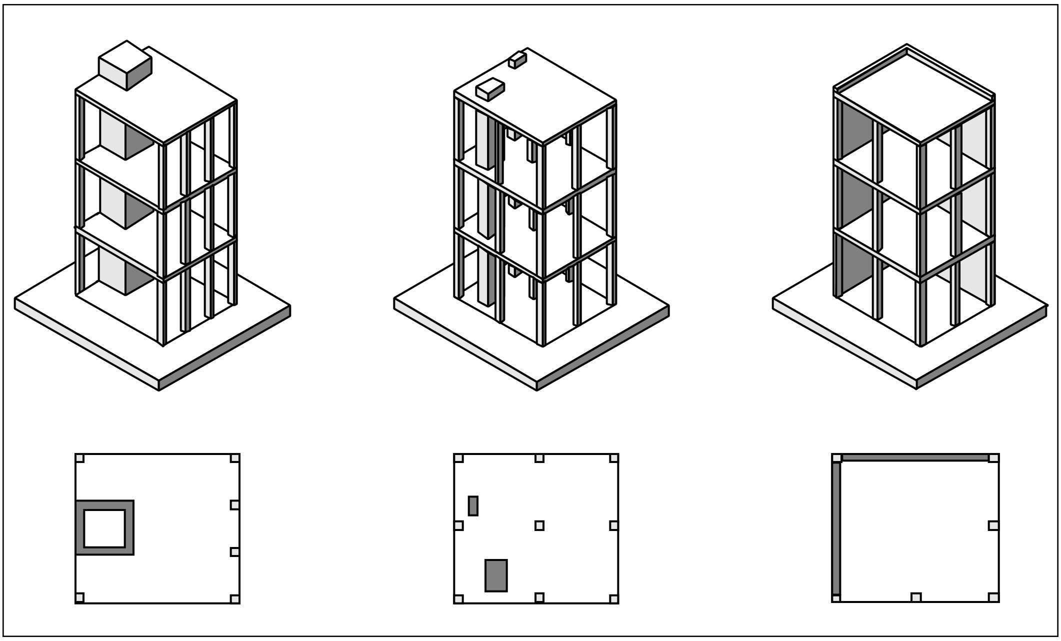
Quantitatively, an eccentricity between the centers of mass and stiffness is considered significant when it exceeds 10% of the horizontal plane dimensions under study. In such cases, corrective measures should be taken in the structural design of the building (see figure 2.8).

Torsion may become even more complicated when there are vertical irregularities, such as setbacks. In effect, the upper part of the building transmits an eccentric shear to the lower part, which causes downward torsion of the transition level regardless of the structural symmetry or asymmetry of the upper and lower floors.

As with all configuration problems, that of torsion should be addressed starting with the design of space and form of the building. The necessary corrections to the problem of torsion may be summarized as follows:

- Torsion should be considered inevitable due to the nature of the seismic event and the characteristics of the structure. For this reason, the suggestion is to provide buildings with so-called perimetric stiffness, which seeks to brace the structure against any possibility of rotation and distribute torsional resistance among several elements.
- In order to control torsion, the layout of the structure in plan and elevation must be studied carefully, as well as the presence and need for isolation of the nonstructural partition walls that could structurally intervene during an earthquake. Finally, the objective of these measures should be to provide to the structure the greatest possible symmetry of stiffness with respect to the mass.

Figure 2.8.
Eccentricity between centers of mass and stiffness increase effects of torsion.



Seismic-resistant design

Seismic-resistant design of structures is more complex than the design for static gravity loads, due to some of the following factors:

a) The random nature of the characteristics of an earthquake;
b) The uncertainty of the response of the structure, due to the heterogeneous quality of materials, interactions with nonstructural elements, variation in service loads, variations in construction, etc.;
c) The failure and energy dissipation mechanisms that entail the least risk for human life and property;
d) The social cost entailed in the failure of buildings, especially those essential for responding to disasters, as in the case of hospitals.

Seismic-resistant design should attempt to take into account all of these aspects.[6] Normally, design codes address some of these problems by means of simple quantitative formulas for overall or localized safety considerations. Often, mindless adherence to these quantitative formulas in the design of structures causes the basic principles behind such simplifications to be forgotten or disregarded. However, in the design of any building, and especially essential facilities such as hospitals, the implications of each important decision must be assessed in the light of the principles and advances of seismic engineering.

Below is a summary of these implications of seismic design of hospitals.

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[6] Asociación Colombiana de Ingeniería Sísmica, *Normas colombianas de diseño y construcción sismo resistente NSR-98* (Law 400 of 1997, Decree Law 33 of 1998), Bogotá, 1998.

Design spectra

In the design spectra recommended by seismic resistance codes, decisions must be made about:

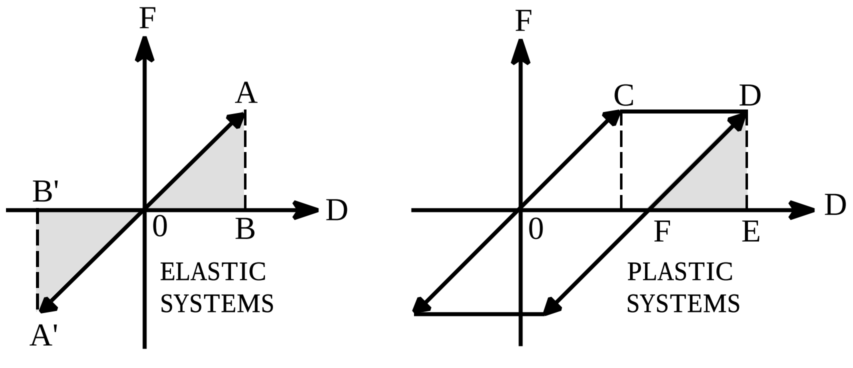
a) *The probability of exceeding the design earthquake in a period of time considered to be the average useful life of buildings*. Normally, this is considered to be a probability of 10% in an average useful lifetime of 50 years. In the case of hospitals, however, the useful life far exceeds that number. Construction of hospital facilities is decidedly less common than housing and other types of buildings. This is a critical issue in developing countries, where construction of large hospitals is rare because of the high costs involved. Health facilities are meant to last a very long time in some countries, and careful thought must be given to their design.

b) *Dominant frequencies and maximum responses.* Normally, the spectra of earthquakes exhibit narrow frequency ranges in which the maximum responses are found. However, to dispel the uncertainties associated with the distance from the occurrence of the event and its frequencies, design spectra present a broad range of maximum responses as well as amplification factors of the responses in soft ground with respect to responses in firm ground. These ranges are based on performance observed in various locations around the world. In the case of hospitals buildings a design spectrum should be prepared in accordance with the geological and geotechnical characteristics of the construction site.

Nonlinear performance

The criteria for traditional design of buildings subjected to strong earthquakes have been to allow the materials some degree of nonlinear response for the purpose of absorbing energy through permanent deformations. Figure 2.9 illustrates this criterion for an elasto-plastic system. The line OA represents the maximum stress—maximum deformation diagram of a perfectly elastic system during a given earthquake, while the line OCD represents an elasto-plastic system. Several hypotheses exist for the simplification that must be assumed to evaluate the performance of an elasto-plastic system in a simple manner.

Figure 2.9.
Absorption and dissipation of energy



The structure must be designed for less stress than is produced by the response of the elastic system. If an elastic analysis is done with the stresses obtained in this manner, some distortions will be obtained that, in turn, must be multiplied by the ductility factor to estimate the maximum deformation of the structure, which is of great importance for the study of the performance of nonstructural elements and the stability of the different floors. The structural elements must then guarantee that these inelastic distortions can be achieved. For this reason, these elements should have sufficient ductility, by means of mechanisms that will be discussed in the next section.

Many construction codes make the mistake of considering a reduction of stresses due to inelastic performance only in relation to the maximum deformation reached at any instant of the earthquake, or to the maximum energy dissipated in a cycle, without considering its duration. This ignores important factors such as the progressive fatigue of the materials, as well as the degradation of stiffness, reduced resistance, the progressive increase of deformations, and, therefore, progressive collapse. For this reason increasing emphasis is being placed on design methods that consider the total duration of an earthquake, generally by total energy dissipated or the number of load cycles.

Ductility

The simplified nonlinear methods of design demand the structure to undergo large deformations without collapsing. However, design methods must also ensure that deformation will not affect or cause damage to the building content (nonstructural elements).

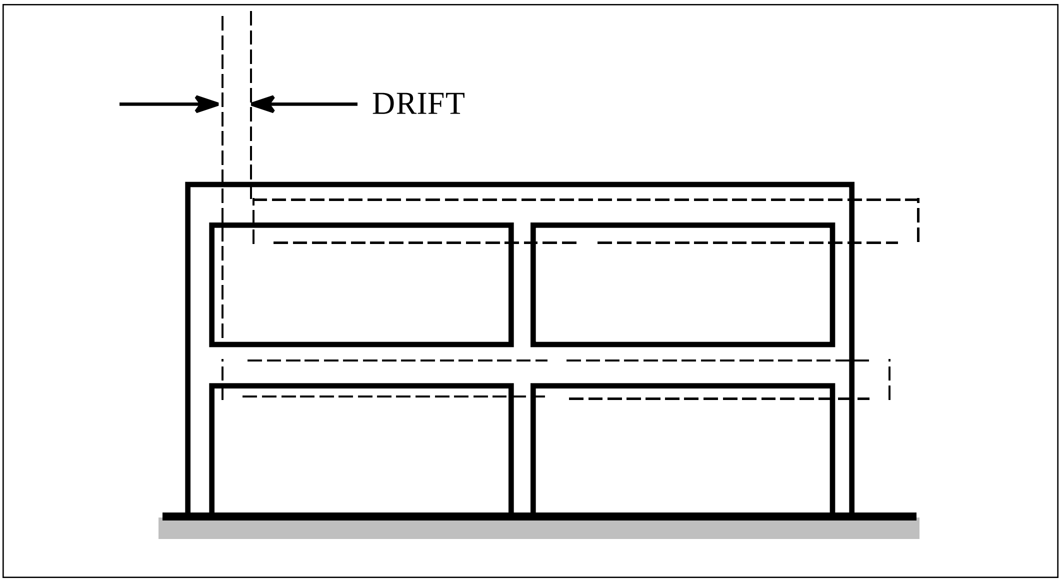
In the design of reinforced concrete structures, the following basic criteria must be taken into account in order to obtain the required ductility:

- *Confinement.* Confinement of concrete guarantees preservation of the material under the alternating stress that occurs during earthquakes. This mechanism allows for greater inelastic deformations than are possible in a structure in which the concrete fails.
- *Controlling shear failure.* Shear failure seriously compromises the integrity of any element of reinforced concrete. For this reason the design codes generally require that shear resistance be greater than flexure resistance. This is achieved by using as a shear design a value that at the very minimum corresponds to the plastic yielding from flexure at the end connections.
- *Controlling the reduction in available ductility due to axial load.* Axial compression load drastically reduces the ductility available in a concrete element subject to this load. The phenomenon, which is more severe in columns than in structural walls, can be attributed to the fact that with heavier compression loads the working stress of the steel is reduced. This can occur with working stress values smaller than yield stresses, which implies an inadequate use of steel in order to develop large inelastic distortions and to dissipate energy in this manner. However, it is not always possible to design the sections of columns so that there are heavy traction stresses on the steel, for architectural and economic reasons.

Drift (relative displacement between floors)

In principle, large lateral displacements between stories, or "drift", put the entire safety of the building in danger, due to the damage that it can represent to nonstructural elements. Depending on the extent of displacement, partial or total collapse of the building can occur (figure 2.10).

Figure 2.10.
Drift and stability



The damage to nonstructural elements attached to the structure is particularly serious in the case of hospitals, and this is covered in detail in the following chapter. For the time being, it is necessary to keep in mind that this damage is associated with the value of the relative inelastic displacement of one level with respect to an immediately contiguous one, or drift. It has been established that drift values higher than 1 or 1.5 per thousand of the clear height between the two levels are not desirable. However, this limit depends heavily on the fragility and resistance of the materials of the nonstructural elements.

Calculating appropriate values of inelastic displacement is of major importance for a suitable analysis of drift and stability. Being conservative in this aspect is more desirable in the case of hospitals than in other structures, due to the implications that damages to nonstructural and structural elements have for the occupants and the community in general.

Duration of the earthquake

The effect of the duration of an earthquake on structural behavior has traditionally been ignored in design codes. This is due in part to the fact that the accelerations spectrum is insensitive to the duration of the earthquake, since it collects information only with reference to the maximum response acceleration at some point during the earthquake and ignores what happens afterwards. However, in long earthquakes complex phenomena of degradation of stiffness and resistance can occur, due to the high number of load cycles that the structural elements must endure. Therefore, the design should be different for short and long earthquakes, regardless of the design acceleration.

According to studies conducted in different countries, the duration of an earthquake correlates with its magnitude and the distance from the epicenter. In contrast, ground acceleration decreases with this distance. There can be earthquakes of equal peak acceleration that would produce the same design acceleration spectrum but large differences in duration and which would produce harmful effects that would not be detected by this spectrum.

In light of the above, the design of hospitals must take into account seismological information related to magnitudes and epicentral distances. If there are sources of high probable magnitudes located at great epicentral distances, much longer and possibly more destructive earthquakes can be expected than from nearby earthquakes. The 1985 earthquake in Mexico City is an example not only of ground amplification effects but also of the effects of long duration, due to the high magnitude (8.1) and large distance from the epicenter (350 km).

Analysis of structural vulnerability

The above sections have dealt with the aspects that must be considered in the planning, analysis, and design of buildings in accordance with recent theories on seismic resistance. In these cases, the most detailed inspection possible of the ability of the structure to resist moderate and severe earthquakes becomes imperative. Before retrofitting a structure, an analysis of the building's existing resistance and ductility, as well as the functional, organizational and administrative vulnerability of the hospital, must be carried out.

A vulnerability assessment seeks, among other things, to determine the susceptibility or the level of damage expected in the infrastructure, equipment and functionality of a hospital facility from a particular disaster; therefore, to initiate a vulnerability assessment, the phenomenon or phenomena to be considered must be characterized.

In the case of earthquakes, it is worthwhile to select and characterize those events that could arise during the lifetime of the hospital facility. Frequent, low-magnitude earthquakes can affect nonstructural elements; on the other hand, less frequent but more violent earthquakes can affect structural as well as nonstructural elements.

The principal methods for structural assessment are discussed below. Such an assessment will be inadequate if it is not accompanied by a detailed review of the nonstructural elements.

The international literature presents several methods for conducting seismic vulnerability analysis of a building; examples are listed in the bibliography of this publication. In general terms, however, the methods can be classified as qualitative and quantitative:

- Qualitative methods are generally used to evaluate a large sample of buildings or to corroborate the level of safety in a given structure.
- Quantitative methods are utilized when the importance of the building merits it, or rather when qualitative methods have not been able to assess the safety of the building.

Qualitative methods

Qualitative methods are designed to evaluate in a rapid and simple manner a group of buildings, and to select those that merit a more detailed analysis. They can be used to quantify seismic risk in a broad area of a city, but their results cannot really be taken as conclusive in any particular case[7], except to the extent that they corroborate the already established safety level of a building. Boxes 2.2 and 2.3 describe national programs using qualitative and quantitative methods is assessing hospitals.

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[7] Centro Regional de Sismología para América del Sur (CERESIS), *Programa para la mitigación de los efectos de los terremotos en la Región Andina*; SISRA Project, Lima, 1985.

Box 2.2. Vulnerability assessment: a tool for setting health sector priorities in Chile

The 1985 earthquake in Chile was especially destructive to the country's health infrastructure. The event damaged 180 of the 536 establishments in its area of influence, and left 2,796 of the 19,581 available beds out of service. As a result of this experience and the importance given to the subject of natural disaster prevention in that country in recent years, a program to identify and assess hospital vulnerability was undertaken for the purpose of setting priorities and reducing the risk to health care infrastructure.

Relying upon a multidisciplinary team, the political commitment of the authorities, and scientific information on the level of seismic hazard in the country, a project was formulated with the objective of identifying measures to reduce the vulnerability of the most important hospitals from each of the 26 health services divisions in the country.

An initial sample of 26 hospitals was chosen; of these a group of 14 was finally selected as a representative sample of the different types of construction and the level of exposure to seismic hazards. The development of this methodology was useful in two ways: it provided a tool that did not exist at the time in Latin America, and it identified individual problems and solutions for each hospital studied.

Each of the hospitals was the focus of an intense assessment, including structural, nonstructural, functional, and organizational aspects. The assessment's starting point was the integrity of the structure and the safety of its occupants.

The project included the following activities:

- A description of the health system;
- A brief description of seismicity in Chile;
- Training of personnel;
- Analysis of structural and nonstructural vulnerability;
- Estimation of the vulnerability of the area and development of mitigation plans.

The effectiveness of the assessment was tested when an earthquake with a magnitude of 7.3 on the Richter scale hit the city of Antofagasta on 31 July 1995. The city hospital, which had been evaluated a few days earlier, partially lost its operating capacity due to broken water pipes, broken windows and lighting systems, damage to equipment (hemodialysis and boilers), and general damage in the structural and nonstructural systems. Immediate evacuation of the hospital was considered.

***Source: Boroschek, R., M. Astroza, Cl. Osorio, E. Kausel, "Análisis de vulnerabilidad y preparativos para enfrentar desastres naturales en hospitales en Chile", Universidad de Chile, Study prepared for PAHO/WHO – ECHO, Santiago, Chile, 1996; Chile, Ministry of Health, Seminario sobre mitigación de vulnerabilidades hospitalarias, Universidad de Chile, Facultad de Ciencias Físicas y Matemáticas, Santiago, 1997.**

Box 2.3. Assessing a city's hospitals: experience in Ecuador

Ecuador has an extensive history of destructive earthquakes. In the city of Guayaquil, located 200 km from the fault where the Nazca and South American tectonic plates collide, one can find 90% of the alluvial or soft soils that can amplify earthquakes with epicenters 200 or 300 km away. This effect can have a major impact on reinforced concrete buildings with between 5 and 15 stories. Two such buildings collapsed in a 1942 earthquake measuring 7.9 on the Richter scale. In 1980, an earthquake measuring 6.1 on the Richter scale caused moderate damage to buildings of poor quality.

On the basis of a study called "Seismic vulnerability of important structures in the city of Guayaquil" carried out by the Institute of Research and Development of the Faculty of Engineering of the Catholic University of Guayaquil (IIFI-UC), it was decided to conduct a vulnerability assessment of the city's hospitals. Basic scientific information was relied upon, and the city was divided into microzones. The study was conducted by professionals from the IIFI-UC, with the input of hospital directors, the unconditional support of the National Civil Defense Authority, and technical contributions from PAHO.

The initial objective was the execution of preliminary vulnerability assessments for the 16 most important hospitals of the city. This number was later increased to 20, 12 of which were quantitatively evaluated and the remaining 8, qualitatively evaluated. The methodology employed included the following activities:

- *Structural assessment and census of the hospitals.* Those structural variables were investigated that had the greatest bearing on the seismic resistant performance of the hospitals, as well as structural and nonstructural damages produced by previous earthquakes. An inventory of hospital services was carried out, including the existence of emergency plans.
- *Selection of the 16 most important hospitals of Guayaquil.* By definition, these were facilities with necessary services for large-scale response to an emergency caused by a natural disaster. The final sample was selected on the basis of the recommendations of Civil Defense Authority.
- *Definition of the probable seismic demand.* This was based on the response spectra obtained from the seismic microzoning of the city.
- *Experimental assessment of the resistance of concrete from a sample of 10 hospitals.* Since 95% of the 16 hospitals have reinforced concrete structures, cores were extracted from the concrete columns of the ground floor in 10 of them and underwent simple compression assays.
- *Experimental assessment of dynamic characteristics of the 16 most important hospitals.* The objective of this phase was to evaluate the behavior of the nonstructural elements in the seismic response of the building through measurement of dynamic characteristics for environmental vibrations.
- *Quantitative mathematical analysis of the seismic-resistant performance of 12 hospitals.* This was accomplished by analyzing flow resistance ductility, failure mechanisms and deformation of floors.
- *Qualitative and quantitative diagnoses of structural and nonstructural vulnerability*.
- *Training of technical personnel in charge of emergencies in the hospitals.* Meetings were held to share information on activities and preliminary results of the project. Officials of the Ministry of Health and Civil Defense participated.
- *Categorization of the seismic resistant safety and operating level of the hospital system.* A six-level scale was introduced, with the first category corresponding to slight nonstructural damage and the sixth corresponding to the possibility of total collapse.
- *Conclusions and recommendations to reduce structural and nonstructural vulnerability.* Practical, short-term, and low-cost actions were presented.

This project succeeded in gaining public support thanks to thorough coverage by local media of the different phases of the project. Perhaps the most significant result was the communication and understanding afforded between the project team, made up primarily of engineers and health professionals.

Source: Argudo, J. and R. Yela, Vulnerabilidad estructural de hospitales de Guayaquil - Ecuador, Report prepared for PAHO and ECHO, Guayaquil, 1995.

Some of these methods constitute the first level of assessment of the qualitative or analytical methods. Examples are the Japanese method[8], the assessment designed by Iglesias[9] in the case of Mexico City, and the ATC-21 method[10]. The building receives a rating in accordance with aspects such as its condition, the irregularity of its plan and elevation, soil type, etc. Such ratings generally do not demand very sophisticated calculations. However, the first level of the Japanese method does require the computation of certain variables which are closely related to the higher levels of analysis. The annex to this book presents some of the qualitative methods most frequently used in Latin America to determine the seismic vulnerability of hospital facilities.

Quantitative methods

For the post-seismic recovery of essential buildings, the more rigorous quantitative methods are desirable. As mentioned earlier, these methods also serve to broaden the results obtained from qualitative methods, when these do not provide definitive findings about the safety of the building.

In order to perform a vulnerability assessment using quantitative methods, it is necessary to have certain basic information: characteristics of the materials utilized in the building, attributes of the soil type, and structural plans, among other information. Quantitative assessments generally are performed using mathematical models of the structure, which consider the following:

- Interaction of the structure with the nonstructural elements;
- The loads to which the structure is submitted;
- Analysis of the different types of earthquakes that can occur.

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[8] Hirosawa, M., "Assessment of seismic safety and guidelines on seismic retrofitting design of existing reinforced concrete buildings." Paper presented at the VI Seminar on Seismology and Earthquake Engineering for Structural Engineers, Tokyo, 1976. See also Hirosawa, M. et al., "Seismic evaluation method and restoration techniques for existing and damaged buildings developed in Japan". Paper presented at the IDNDR International Symposium on Earthquake Disaster Reduction Technology, Tsukuba, Japan, 1992.

[9] Iglesias, J., Evaluación de la capacidad sísmica de edificios en la Ciudad de México, Secretaría de Obras, Mexico, 1986.

[10] Applied Technology Council, Rapid visual screening of buildings for potential seismic hazards: a handbook (ATC-21 Report), Redwood City, 1988 (FEMA Report 154, July 1988).

Box 2.4. Applying scientific assessment methods in Colombia

Vulnerability assessments were performed of the Evaristo García Departmental Hospital in Cali and the University Hospital of Caldas in the city of Manizales, Colombia. Both studies were conducted by specialists from the Colombian Seismic Engineering Association (AIS) who applied several methods for the purpose of comparison. In the first instance, the ATC-22 method, the Japanese method and the Akiyama energy method were used. In the other case, a method developed by AIS in 1985 (known as AIS-150) was used. This method was later included as Chapter A.10, "Analysis of the seismic vulnerability of existing buildings," of the Colombian standards for seismic resistant design and construction.

Apart from the contribution that this project made to the application and development of technical methodologies, one of the most interesting aspects was the enthusiasm and awareness that the studies generated in hospital and health care authorities of the two cities. The local administrations later took on, with their own resources, the second phase of the studies, which was the design of seismic-resistant retrofitting and rehabilitation procedures.

In spite of the fact that rehabilitation studies of hospitals had already been conducted before in the country due to problems encountered relating to deterioration and remodeling of facilities, these two studies were the first to explicitly treat the subject of seismic vulnerability of hospitals in terms of prevention. They served as examples for the Ministry of Health and the National Agency for Disaster Prevention and Response, organizations that initiated the promotion of preventive retrofitting of hospital facilities in the areas of the country with the greatest seismic hazard.

Source: Asociación Colombiana de Ingeniería Sísmica (AIS), Análisis de vulnerabilidad sísmica del Hospital Universitario de Caldas, Comité de Vulnerabilidad y Riesgo Sísmico AIS-400, Manizales 1992. See also AIS, Análisis de vulnerabilidad sísmica del Hospital Departamental Evaristo García, Comité de Vulnerabilidad y Riesgo Sísmico AIS-400, Cali, 1992.

Measures to reduce structural vulnerability

Many existing hospital buildings do not comply with the necessary technical requirements to ensure continued functioning after natural disasters. Their vulnerability to certain natural hazards can greatly exceed currently accepted levels. Experience shows, however, that the safety of existing structures can be improved with the application of relatively inexpensive measures. Mitigation measures considering the occupation characteristics of the facility and in accordance with the current engineering requirements of each country should be carried out to reduce risk and guarantee adequate performance.

Retrofitting

Assessing the condition of an existing building may raise serious doubts about its ability to withstand seismic events[11], which can lead to the need for retrofitting or rehabilitating the building totally or partially, in order to reduce its vulnerability before an event occurs. This is mandatory for essential buildings that respond to the emergencies derived from earthquakes.

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[11] Asociación Colombiana de Ingeniería Sísmica (AIS), *Adición, modificación y remodelación del sistema estructural de edificaciones existentes antes de la vigencia del Decreto 1400/84,* Norma AIS-150-86, Bogotá, 1986.

The execution of a retrofitting project should follow a detailed work plan that guarantees the least impact on the normal functioning of the hospital in each stage of the process. This requires the hospital administration to closely coordinate the work of medical treatment and hospital maintenance departments during the process. This coordination has proved to be very important in completing the project in a given timeframe and without interfering with ongoing provision of health services.

Retrofitting design

The analysis, design and construction of any necessary retrofitting must be carried out bearing in mind the following aspects:

1. *Physical and functional aspects.* The retrofitting should not affect the hospital's day-to-day operations.
2. *Aspects of structural safety.* It is essential to reduce vulnerability to acceptable levels, so that the hospital can continue to function after an earthquake
3. *Construction techniques.* Retrofitting should be carried out using construction techniques that have the least impact on normal functions of the hospital, since it would be difficult to shut it down for repairs.
4. *Cost of the intervention*. The cost of retrofitting cannot be ascertained unless a detailed design of the structural solution and of its implications for the nonstructural elements is carried out. Retrofitting costs are usually relatively high, especially when done in a short period of time. However, if the work is done in stages, resources can be used within the range of expenditures for hospital maintenance.

In accordance with the above, the intervention of the structure should seek to reduce the existing vulnerability by responding to existing performance problems. The structural retrofitting should:

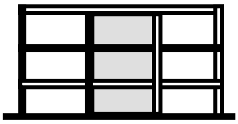
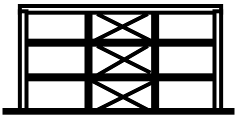
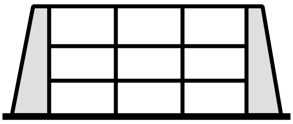
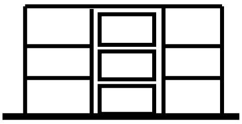
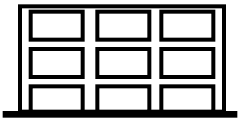
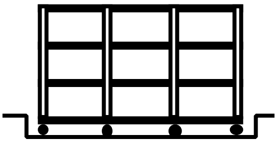
- Increase resistance;
- Increase stiffness and therefore decrease deformation;
- Increase ductility;
- Attain an adequate distribution of the stresses between the different resistant elements, as much in the ground plan as in the vertical configuration.

The usual systems of structural reinforcement tend to incorporate the following additional elements (see figure 2.11):[12]

Exterior structural walls

This solution is generally employed when space limitations and continuity of building use make work on the periphery preferable (see figure 2.12). To ensure the transmission of stresses through the diaphragm to the walls, collector beams are used on the edges of the slab. This is not recommended for very long buildings.

Figure 2.11.
Conceptual solutions for structural reinforcement

Reinforcement measure		**Benefits**
Interior walls		Increased resistance and reduced drift
Addition of diagonal bracing		Increased resistance and reduced drift
Addition of buttresses		Confinement and reduced drift
Addition of interior or exterior moment-resisting frame		Confinement and reduced drift
Complete rebuilding		High seismic-resistant capacity and control of typical types of damage
Isolation at the base of the building		Protection of the building through control of shaking

AIA/ACSA

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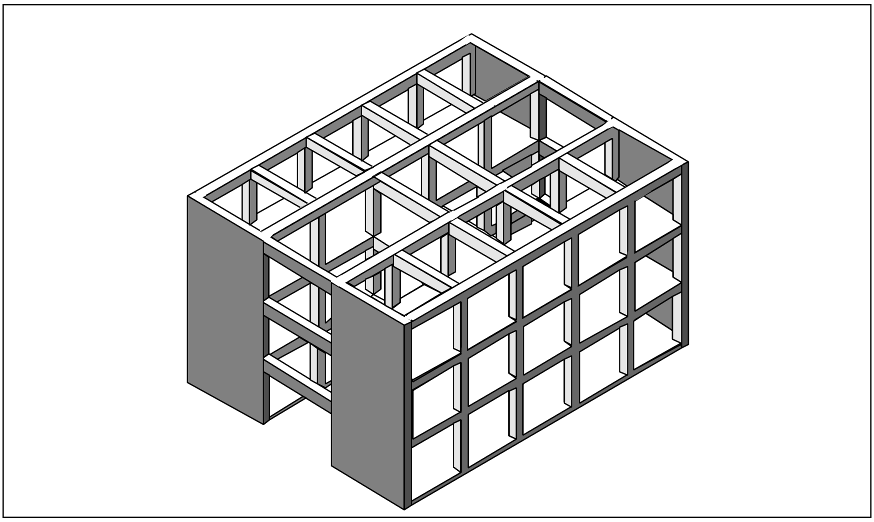
[12] Iglesias, J., *Evaluación de la capacidad sísmica de edificios en la Ciudad de Mexico*, Secretaría de Obras, Mexico, 1986.

Figure 2.12.
Structural walls in the periphery

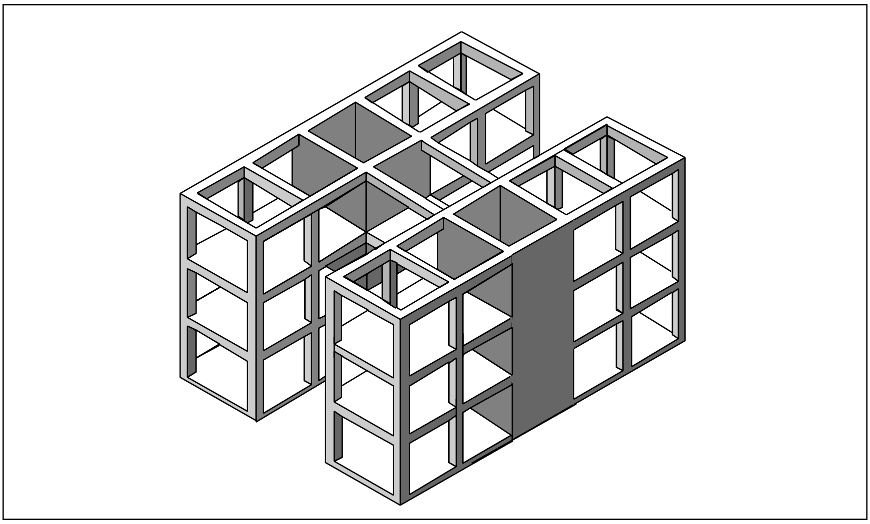


T. Guevara

Interior structural walls

When it is possible to work inside a building, these walls are an alternative that should be considered, particularly in long buildings where the flexibility of the diaphragm must be reduced (see figure 2.13). They are generally inserted through perforations in the diaphragm, through which the reinforcement bars pass. This method of retrofitting was used in the National Children's Hospital of Costa Rica.

Figure 2.13.
Interior structural walls



T. Guevara

Frame walls

Both inside and outside buildings, a practical solution to the problem of stiffness and resistance is to fill frame openings with concrete or reinforced masonry walls. Due to the connection with the column, the stresses on them will change substantially. If the reinforcement of the column is sufficient for the new situation, the connection with the wall can be done solely with soldered bolts. Otherwise, a sheathing of the column, monolithic with the wall, should be constructed.

Buttresses

Unlike exterior building walls, buttresses are placed perpendicular to the face of the building. Aside from providing rigidity, they are useful in preventing tall, narrow buildings from overturning. The Cardiology Hospital of the Mexican Social Security Institute (IMMS) uses this type of reinforcement (see photograph 12). Due to space limitations, however, these are not always feasible.

C. Osorio

Photograph 12.The Cardiology Hospital of the Mexican Social Security Institute was retrofitted using buttresses following the 1985 Mexico City earthquake.

Braced frames

Another frequent solution consists of including several steel frames with diagonals firmly anchored to the diaphragms, as a substitute for stiff walls (see photograph 13).

Sheathing of columns and beams.

Used for frame systems, this is generally applied on most of the columns and beams in a building in order to increase their stiffness, resistance and ductility alike.

Construction of a new framed system.

On occasion it is possible to carry out a total restructuring by attaching new external perimetric frames to the old structure, like those used in the reinforcement of the Hospital Mexico in San José, Costa Rica (see photograph 14). Usually this is combined with the incorporation of internal structural walls perpendicular to the longitudinal direction of the frames.

Isolation and control of vibrations.

There has been a marked increase in the use of techniques to isolate the foundation and control vibration in structures located in seismic-prone areas. This is an alternative to methods that aim to dissipate energy by tolerance of damage by structural elements entering into the nonlinear range. These systems will undoubtedly be very important in the construction of buildings in general, due to the growing demand for structural and nonstructural safety in the face of strong earthquakes and for comfort amidst environmental vibrations.

O.D.Cardona

Photograph 13. Reinforcement with diagonals.

M. Cruz

Photograph 14. Use of external perimetric frames for reinforcement of the Hospital Mexico in a project carried out by the Costa Rican Social Security Fund (CCSS).

Box 2.5. A demonstration of political will in Costa Rica

Vulnerability assessments of the hospitals in Costa Rica were begun in 1984 as part of a research project at the University of Costa Rica and in response to growing public concern about the recurrence of the disaster experienced in 1983 in San Isidro de Pérez Zeledón.The School of Civil Engineering initiated this work thanks to incentives provided by the National Emergency Fund and to the interest shown by officials of the Costa Rican Social Security Fund (CCSS). PAHO/WHO was another driving force of this initiative, since it represented a new field of research in Latin America.

After the study of the Calderón Guardia Hospital in 1984,the University requested financing from the National Council of Scientific and Technical Research (CONICIT) to study the vulnerability of all the hospitals in the country. CONICIT partially approved the financing requested so the University began the project by studying Hospital Mexico in 1986.This funding was attained in part due to the support given the initiative by physicians of the CCSS.The Hospital Mexico study was the first on integral seismic vulnerability in the country, addressing different levels of risk for structural,nonstructural,administrative and functional aspects of the hospital.

The restructuring of the three buildings that constitute the hospital complex consisted basically of positioning additional columns and beams on the exterior concrete frames and isolating all of the structural walls. In addition, the walls of the emergency stairs were connected to the main structure to decrease the possibility that they would collapse. With this alternative, the stiffness of the buildings was increased which would decrease lateral deformation due to earthquakes; this in turn meant reduced risk of nonstructural and structural damage (see figure 2.14).

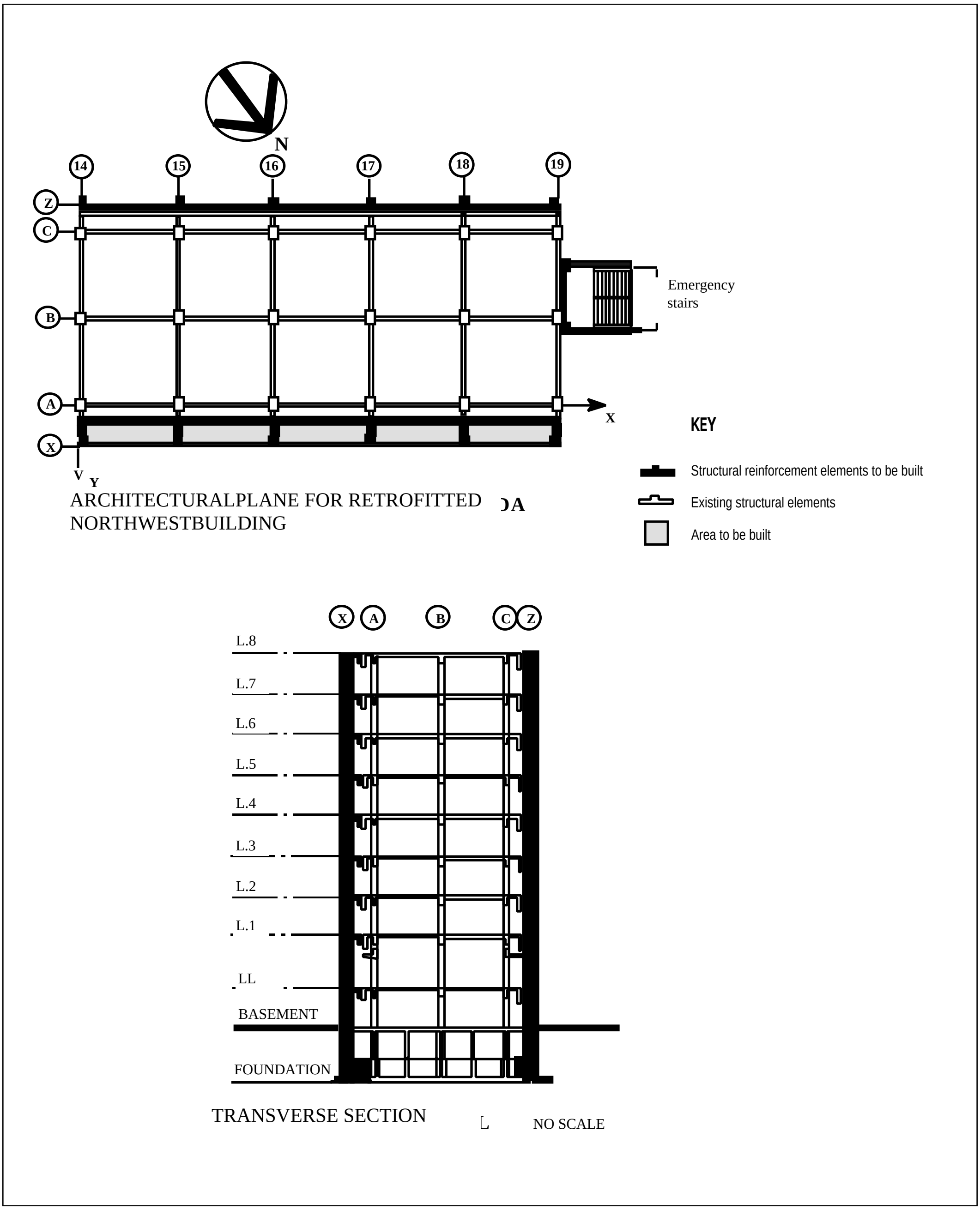
The reinforcement work began in May 1989 and the process required 31 months to complete. The cost of the work was US$ 2,350,000 dollars,which represented 7.8% of the value of the hospital.The hospital had to reduce its number of beds from 600 to 400 during the process, with a consequent increase in the number of patients waiting for medical attention.

Apart from the Hospital Mexico, the CCSS also conducted vulnerability assessments, retrofitting design and rehabilitation of the Hospital de Niños (Children's Hospital) and the Hospital Monseñor Sanabria. Difficulties in the construction process arose in these two cases due to inadequate coordination with hospital administration. However, these experiences permitted the identification of the aspects of coordination and multidisciplinary work that must be taken into account in order to avoid overspending and problems related to the ongoing performance of the facilities.

Several earthquakes have occurred since 1990 that have demonstrated the good fortune of having reinforced these facilities. Particularly, it is believed that the Hospital Monseñor Sanabria would not have survived the earthquake of 25 March 1990.On the other hand,the damages sustained by the Hospital Tony Facio, which had not been reinforced when the earthquake of 22 April 1991 occurred,confirmed the importance of continuing the assessment and retrofitting process. In fact,the CCSS formally incorporated seismic-resistant design and vulnerability assessments into the formulation phase of new projects. In the design of the new Hospital San Rafael de Alajuela, for example, state-of-the-art techniques were used.The design of this hospital is an example of multidisciplinary work in which seismology experts, scientists, engineers, architects, and public health personnel all participated.

Sources: Cruz,M. F.,"Comportamiento de hospitales en Costa Rica durante los sísmos de 1990",Taller Regional de Capacitación para la Administración de Desastres,Bogotá,1991.Cruz,M.F. and R.Acuña, *Diseño sismo-resistente del Hospital de Alajuela: un enfoque integrador*, International Conference on Disaster Mitigation in Health Facilities, Mexico 1996.

Figure 2.14.
Reinforcement of the northwest building of the Hospital Mexico, Costa Rica



Coordinating the retrofitting process

The retrofitting or reinforcing work requires close coordination between hospital personnel and those responsible for design and construction. The director of the hospital, the administrator, those in charge of affected clinical and support services, the chiefs of maintenance and general services, as well as all of the professionals involved in the design and execution of the reinforcement work, must take part in the process. There must be active involvement at all stages of the project, that is during the design, planning and execution of the measures. It should be kept in mind that the same persons may be participating at different times in the coordination efforts.

Lessening the seismic vulnerability of a hospital building is usually more complex than on other types of buildings. Following are some of the aspects that make this type of work different in health installations:

- Normally, the building cannot be vacated in order to carry out the retrofitting;
- The scheduling of the work must take into account the operation of the different health services so as not to cause serious disruptions;
- A wide number of unforeseen tasks can be expected due to the difficulty of precisely identifying details of the construction process before the work begins;
- The effects of structural modifications on nonstructural elements and on architectural finishes should be identified before beginning the process.

In accordance with the above, the development of a retrofitting project should follow a very detailed work plan that addresses the function of the health services at each step of the process. In the same way, the plan should establish proper coordination with administrative personnel, medical services, and hospital maintenance.

Costs of retrofitting

As mentioned earlier, the cost of modifications can only be calculated on the basis of a detailed design of the structural solution and its implications for nonstructural elements. However, it is possible to formulate an advance budget with some degree of precision and that should be adjusted as little as possible during the process.

The additional costs to make a building resistant to hurricanes, earthquakes, or floods can be considered a form of insurance. Studies have shown that the costs of a building designed and built to withstand hazards like earthquakes may increase the total cost of the building by 1% to 4%.

When the costs of preventing damage to specific items is analyzed, the results are dramatic. For example, an electric generator that is severely damaged could result in the loss of power to the hospital and could cost as much as US$50,000 to replace. This situation could be avoided by the installation of seismic isolators and braces to prevent the generator from moving for costs as low as US$250.

In all cases, the high economic and social value of improving the structural performance of vulnerable hospital facilities has been demonstrated. The cost of retrofitting, although it could be considered high in certain instances, will always be insignificant in relation to the provision of health service or in relation to the cost of repair or replacement. One could ask questions such as: The cost of retrofitting would be equivalent to the cost of how many CT scanners? And, how many scanners does the hospital have? The answers could give surprising results, without taking into account the value of all of the other equipment and supplies that are generally in the building, and, of course, the human lives directly or indirectly affected, and the social cost that the loss of health services signifies.

Experience in this area shows that the cost of performing structural seismic vulnerability assessments and designing the required retrofitting may reach between 0.3% and 0.5% of the total value of the hospital. The cost of rehabilitation or retrofitting could range between 4% and 8% of the hospital value (see the example in table 2.2). To illustrate the potential benefit, assume that in a severe earthquake the use of 20% of the existing beds in a hospital would be lost. With an investment in retrofitting of less than 10% of the cost per bed, this loss could be avoided.[13] These figures, while not precise economic assessments, do attest to the cost/benefit ratio achieved when mitigation measures are applied.

Table 2.2.
Cost of retrofitting hospitals in Costa Rica

Hospital	No. of beds	Duration project (months)	Retrofitting cost (US$)	Percentage of of total cost of hospital
Hospital Mexico	600	31	2,350,000	7.8
National Children's Hospital	375	25	1,100,000	4.2
Monseñor Sanabria Hospital	289	34	1,270,000	7.5

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[13] PAHO, *Lecciones aprendidas en américa latina de mitigación de desastres en instalaciones de salud, aspectos de costo-efectividad*, DHA, IDNDR Secretariat, PAHO, Washington, D.C., 1997.

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Chapter 3
Nonstructural Vulnerability

Background

A building may remain standing after a disaster, but be incapacitated due to nonstructural damages. Assessment of nonstructural vulnerability seeks to determine the damage that these elements may suffer when affected by moderate earthquakes, which are more frequent during the life of a hospital. Due to the high probability of earthquakes that could affect the nonstructural components, necessary steps must be taken to protect these elements.

The cost of nonstructural elements in most buildings is appreciably higher than that of structural elements. This is particularly true in hospitals, where between 85% and 90% of the facility's value resides in architectural finishes, mechanical and electrical systems and the equipment and supplies contained in the building. A low-magnitude seismic event can affect or destroy vital aspects of a hospital, those directly related to its function, without significantly affecting the structural components. It is easier and less costly to apply damage mitigation measures to nonstructural elements.

It is not enough for a hospital to simply remain standing after an earthquake; it must continue to function. The external appearance of a hospital might be unaffected, but if the internal facilities are damaged, it will not be able to care for its patients. This section focuses on preventing loss of function due to nonstructural failure, which may also affect the integrity of the structure itself.

Nonstructural elements

The design of any structure subjected to seismic movements should consider that nonstructural elements such as ceilings, panels, partition walls, windows, and doors, as well as equipment, mechanical and sanitation installations, must withstand the movements of the structure. Moreover, it should be noted that the excitation of the nonstructural elements, caused by movements of the structure, is in general greater than the excitation at the foundation of a building, which means, in many cases, that the safety of the nonstructural elements is more compromised than that of the structure itself.

Notwithstanding the above, little attention is generally paid to these elements in the seismic design of structures, to the extent that many design codes do not include standards for nonstructural components. This is evident in the experience of recent earthquakes where structures designed in accordance to modern seismic-resistance criteria performed well, but unfortunately there was a deficient response of the nonstructural elements. If the safety of the occupants of a building, replacement costs, and the losses involved in interrupting the operations of the building itself are taken into account, the importance of seismic design of the nonstructural elements can be understood.

In the case of hospitals, the problem is of major importance for the following reasons:

1. Hospital facilities must remain as intact as possible after an earthquake due to their role in providing routine medical services as well as attending to the possible increase in demand for medical treatment following an earthquake.

2. In contrast to other types of buildings, hospitals accommodate a large number of patients who, due to their disabilities, are unable to evacuate a building in the event of an earthquake.
3. Hospitals have a complex network of electrical, mechanical and sanitary facilities, as well as a significant amount of costly equipment, all of which are essential both for the routine operation of the hospital and for emergency care. Failure of these installations due to a seismic event cannot be tolerated in hospitals, as this could result in the functional collapse of the facility.
4. The ratio of the cost of nonstructural elements to the total cost of the building is much higher in hospitals than in other buildings. In fact, while nonstructural elements represent approximately 60% of value in housing and office buildings, in hospitals these values range between 85% and 90%, mainly due to the cost of medical equipment and specialized facilities.

Experience shows that the secondary effects caused by damage to nonstructural elements can significantly worsen the situation. For example, ceilings and wall finishes can fall into corridors and stairways and block the movement of occupants; fires, explosions and leaks of chemical substances can be life-threatening. The functions of a hospital are dependent on such basic services as water, power and communications. Damage or interruption of these services can render a modern hospital virtually useless.

Nagasawa[1] describes that, as a result of the Kobe, Japan, earthquake in 1995, a significant number of hospitals reported damage due to falling shelves, movement of equipment with wheels without brakes or that were not in use, and falling office, medical and laboratory equipment that was not anchored down. In some cases, even heavy equipment such as magnetic resonance, computerized axial tomography and X-ray equipment moved between 30 cm and 1 m, and equipment hanging from ceilings, such as an angiograph, broke away from its supports and fell, in turn damaging other important equipment.

Nonstructural elements can be classified in the following three categories: architectural elements, equipment and furnishings and basic installations (see table 3.1).

- The architectural elements include components such as non–load-bearing exterior walls, partition walls, inner partition systems, windows, ceilings, and lighting systems.
- The equipment and furnishings include medical and laboratory equipment, mechanical equipment, office furnishings, medicine containers, etc..
- The basic installations include supply systems such as those for power and water, networks for medical gases and vacuum, and internal and external communications systems.

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[1] Nagasawa, Y., Damages caused in hospitals and clinics by the Kobe earthquake, Japan. *Japan Hospital* No. 15.

Table 3.1.
Nonstructural elements to be considered in the vulnerability assessment

Architectural	Equipment and furnishings	Basic installations and services
• Divisions and partitions • Interiors • Façades • False ceilings • Covering elements • Cornices • Terraces • Chimneys • Surfacing • Glass • Attachments (signs,etc.) • Ceilings • Antennas	• Medical equipment • Industrial equipment • Office equipment • Furnishings • Supplies • Clinical files • Pharmacy shelving	• Medical gases • Industrial fuel • Electricity • Telecommunications • Vacuum network • Drinking water • Industrial water • Air conditioning • Steam • Piping • Waste disposal

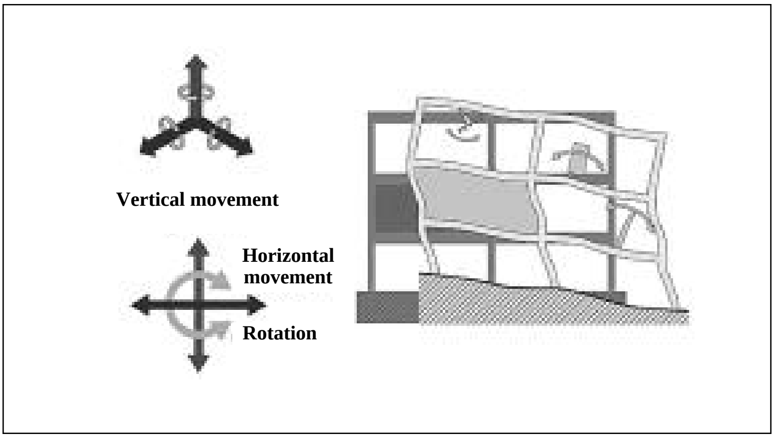
Source: Boroschek R.,Astroza M.,Osorio C., *Capacidad de respuesta de hospitales ante desastres sísmicos: Aspectos no estructurales.* International Conference on Disaster Mitigation in Health Facilities, PAHO, Mexico, 1996.

Methods of analysis

Inventory, inspection and assessment

The vulnerability assessment of the nonstructural elements should be carried out after having obtained the results from assessment of structural vulnerability, since the latter is very valuable for judging susceptibility to damage of nonstructural elements. For example, nonstructural elements may be affected by the deformation of the main structure as determined by drift, that is, the relative lateral movement between two stories. Examples in this category would be partitions or other nonstructural elements between floors or placed between structural walls or columns. When there is no direct interaction due to deformation between the nonstructural element and the structural one, the nonstructural element is considered to be sensitive to acceleration. An example would be mechanical equipment located on a certain floor of a building. Equipment placed on higher stories will be subjected to greater forces due to the performance and movement of the structure during seismic vibration. Figure 3.1 illustrates how structures can respond to seismic shaking.

Figure 3.1.
Response patterns for different sections of building when subjected to seismic forces



Source: McCue, G., A. Skaff, and J. Boyce, Architectural design of building components for earthquakes. National Science Foundation (RANN), Washington, D.C. MBT Associates, San Francisco, California, 1978.

Evaluating basic facilities and equipment

Damages sustained in hospitals from past earthquakes illustrate a variety of problems, some of which are described below:

- Power generator tips over causing an interruption in the hospital's power supply and resulting in the failure of life-support systems. This occurs because the anchors to the foundation are corroded and not strong enough to prevent the generator from falling.
- High voltage transformers tilt or tip completely over and oil is spilled. The emergency energy supply is interrupted.
- The telephone switchboard moves, causing a temporary interruption in the hospital's communications.
- Oxygen and flammable gas cylinders tip over, and their contents leak, creating risk of explosion or fire.
- Storage shelving tips over and bottles in the cabinets break. The contents are spilled, representing a loss of necessary medicines and biological samples.
- Laboratory equipment falls over and instrumentation systems break.
- Piping for water, clinical gas and/or steam supply systems break inside the hospital. This generally occurs in areas where these pipes intersect with expansion joints or when they are embedded in partition walls that are damaged by earthquakes.

Among the nonstructural hazards that can affect the life or the health of the occupants of a hospital the following should be mentioned:

- Furniture with sharp edges
- Glass that can fall in transit areas
- Objects that fall from shelves, cabinets and ceilings

- Impact from objects that slide or roll along the floor
- Inhalation of toxic or medical gases
- Contact with corrosive or dangerous liquids
- Steam burns
- Fire
- Disconnection or failure of life-support systems
- Inability to evacuate

To evaluate these elements, a general inventory is made of the equipment considered to be strategic because of certain characteristics (e.g., size, weight, shape), its cost, its importance for essential hospital services, or because of the condition of fasteners.

The first step in the implementation of a nonstructural mitigation program for a hospital is to carry out a systematic, thorough inspection of the facility to evaluate existing hazards. Three risk levels are recommended for classifying the hazard posed by the failure of nonstructural elements:

- Risk of loss of life;
- Risk of loss of equipment and property;
- Risk of functional loss.

Those elements whose failure or malfunctioning due to an earthquake could mean loss of life or injury to the occupants of the hospital will be classified as nonstructural elements that present a risk to life. On the other hand, those elements that represent a risk of loss of goods will be those that, if damaged, would mean a significant loss of assets to the health facility, but would not affect the occupants or the functioning of the building in a significant manner.

A high risk for human life, for example, could be a component mounted on the wall above a patient that could fall, injuring or killing the patient. If equipment is placed on shelves without fastenings, for example, the risk of it being thrown off by an earthquake is high. If it were to be secured with bolts, but not correctly, with a small possibility of falling, it would be classified as a moderate risk; if it were fastened securely, it would be classified as a low risk.[2]

An example of functional loss might be the power generator. If it is not correctly secured and/or enclosed, it could move enough to disengage its electrical connections and stop functioning. In this case, there would be no property loss since the generator may not have been damaged but simply have come loose from its moorings and connections. It would represent a risk to life since almost everything in the hospital depends on electrical power, including the life-support systems for critically ill patients. This demonstrates that, in some cases, two or three types of risk may correspond to a specific component or system: for human lives, for property and/or functional losses[3].

In order to establish intervention priorities, two parameters are considered:

1. The *vulnerability* of the element or system;
2. The *consequences* of failure or malfunction of the element.

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[2] FEMA, *Instructor's guide for nonstructural earthquake mitigation for hospitals and other health care facilities.* [Materials for course given by Emergency Management Institute, Emmitsburg, Maryland, USA. 1988.] See also FEMA, *Seismic considerations: health care facilities (Earthquake hazard reduction series 35*; FEMA 150). Washington D.C., 1987.

[3] EERI, *Nonstructural issues of seismic design and construction* (Publication No. 84-04). Oakland, California, 1984.

The *vulnerability* of the element or system is the susceptibility to damage, which is measured in terms of:

- Characteristics of ground acceleration;
- Response of the building to acceleration and displacement;
- Size and weight of the element;
- Location of the element in the building;
- Resistance to the building's lateral stresses and relative stiffness of the component with respect to that of the building;
- Characteristics of the connection or joint (or lack of it) between the component and the structure or between the component and another nonstructural support element.

The *vulnerability* of the facilities and equipment can be determined using qualitative and quantitative methodologies[4], and it is measured in three categories: low, medium and high.

- *Low vulnerability*: the evaluated component is reasonably well anchored and there is a low probability that it would be damaged when faced with the design forces and deformation of the building.
- *Medium vulnerability*: the component is anchored, but there is a moderate probability of this fixture failing when faced with the design forces and the deformations of the building.
- *High vulnerability*: the component lacks fastenings or the fastening is inadequate or incorrect, therefore there is a high probability of damage when faced with the design forces and deformation of the building.

The consequences, or an estimate of the effect of the failure or damage to the component, are seen in terms of:

- Location of the component in the building (according to the service or area);
- Occupation of the building or service and the possible impact on the occupants' lives or on the performance of the building or service in case the element fails.

These consequences may also be measured in three categories:

- *Low consequences*: due to its location in the building or due to its type, the damage to the component represents a low probability of causing injuries to the occupants or of interfering with the performance of the facility.
- *Moderate consequences*: due to its location or due to its type, the component represents a moderate probability of causing injuries to the occupants or of interfering with the performance of the facility.
- *High consequences*: the component represents a high probability of causing injuries (and even deaths) to the occupants, or of seriously compromising the facility's performance.

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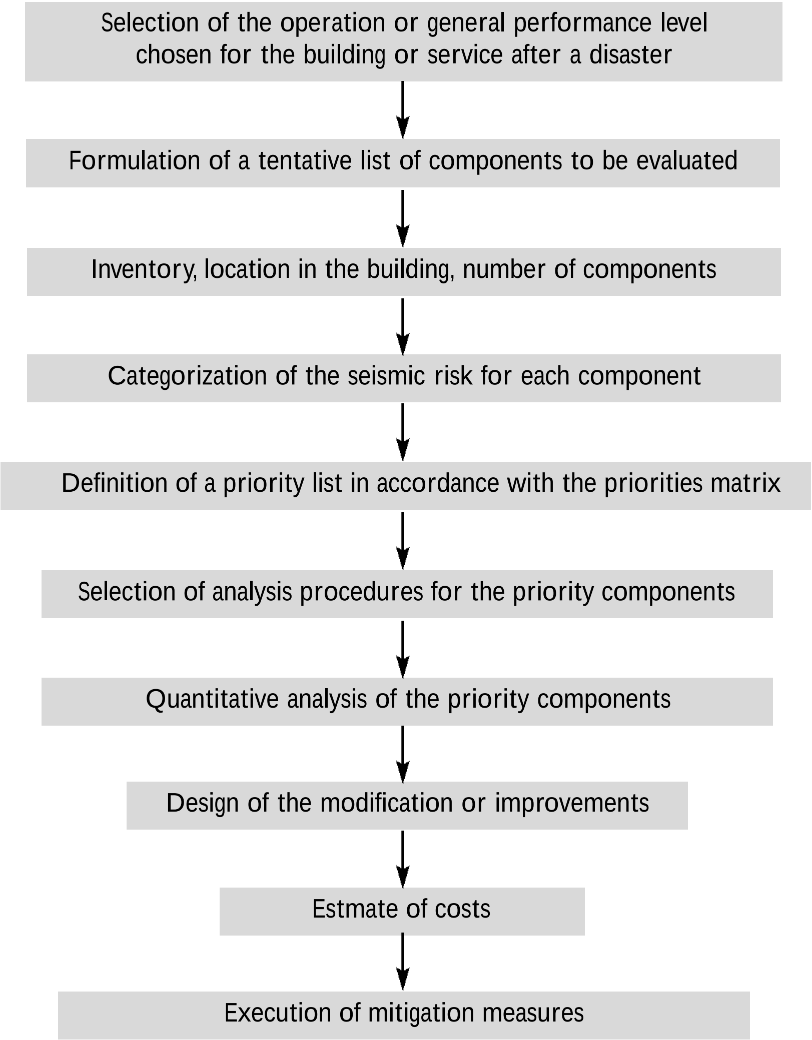
[4] See, for example, McGavin, Gary L. *Earthquake hazard reduction for life support equipment in hospitals.* Ruhnan McGavin Ruhnan Associates, July 1996.

Table 3.2.
Priorities matrix

Vulnerability	**Consequences**		
	High	**Medium**	**Low**
High	1	4	7
Medium	2	5	8
Low	3	6	9

Based on these principles, the assessment procedure is established, which basically follows the steps shown in the flow chart shown in Figure 3.2.

Figure 3.2.
Steps for conducting vulnerability assessment of nonstructural elements



Using these two parameters, a priorities matrix[5] may be defined, as shown in table 3.2. The highest priority for retrofitting or repair of an element is assigned priority "1"; components receiving a "2" have the second highest priority for retrofitting, and so on.

In general, the deficiencies found in the fixings or fastenings of non-priority equipment are notoriously bad, but corrective measures are, in general, easy to apply and are inexpensive. Attention to these details, even for low-priority items is important. If they are not corrected they could cause problems in the provision of the service after an earthquake.

In many cases, people without specialized training can carry out a preliminary assessment of the risk level by asking two basic questions for each nonstructural element under consideration:

- Could the element suffer damage in the case of an earthquake?
- If the element did not function properly, would this cause a problem in the hospital?

This will produce a preliminary list of elements for more detailed consideration. In this phase it is better to be conservative and to overestimate vulnerability. After identifying a nonstructural element that could suffer or cause damage, or which has a negative impact in terms of loss of lives, property and/or functionality, suitable measures must be adopted to reduce or eliminate the hazard.

The tabulation of the types and levels of risk for any element in a hospital may be achieved using a format adapted to the needs of the health facility. An example of a list of evaluated equipment appears in table 3.3. In this table the type of equipment, its characteristics or size, its location according to service, its estimated vulnerability level, the consequences of its failure and priority for attention are detailed. The type of support, fixing or fastening of the equipment is also described.

Examples of another approach to using qualitative methods to assign the level of risk posed to nonstructural components are shown in tables 3.4 and 3.5.

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[5] ATC (Report ATC 33-03), *Guidelines for seismic rehabilitation of buildings*, 75% Submittal, Third Draft, 3 Volumes, Redwood City, 1995; *NEHRP guidelines for the seismic rehabilitation of buildings*, (FEMA 273).

Table 3.3.
Example of a list of evaluated equipment

Type of equipment	**Location**	**Size**	**Vulnerability (V)**	**Consequences (C)**	**Priority**	
Component	*System or service*	*Characteristics*	*(H,M,L)*	*(H,M,L)*	*f (V, C)*	*Type of support*
Oxygen tank	Oxygennetwork	5.5 x 2.3	H	H	1	Legs w/ bolts
Transformer	Power network	3 x 2.5 x 2	H	H	1	Bolts
Circuit boards	Power network	6 x 2 x 1	H	H	I	Simple brace
Anesthesia machine with monitor	Operating theaters	1 x 2 x 2.2	H	H	I	
Water tanks	Drinking water supply		M	H	2	
Gas connection	Gas supply		M	H	2	Without anchors
Emergency generator	Power network		M	H	2	Bolts
Miscellaneous equipment	Clinical laboratory	Various	L	H	3	Tabletop equipment
Telephone switchboard	Communications	5 x 1.4	H	M	4	Simple brace
Shelves	Sterilization center	Various	H	M	4	Without anchors
Freezer	Blood bank	2.5 x 2 x 0.5	H	M	4	Simple brace
Oxygen cylinders	Operating theaters	Various	H	M	4	
Elevator engine	Elevators		M	M	5	Bolts
Elevator controls	Elevators	2.5 x 1	M	M	5	Bolts
Elevator pulleys	Elevators		M	M	5	Bolts
Dialysis unit	Hemodialysis	0.8 x 1.2	M	M	5	Simple brace w/ rollers
Lamp	Plastic surgery	Various	M	M	5	Built in
Incubator	Neonatology	Various	M	M	5	Simple brace w/rollers

Table 3.4
Sample form showing types and levels of risk for nonstructural elements

Facility:___________________________ Expected intensity of earthquake:______________________

Priority	Non structural elements	Location	Quantity	Level of risk			Engineer required	Estimated cost of intervention		Observations
				Risk to life	Loss of property	Loss of function		Unit	Subtotal	
2	Air conditioning	Ceiling	1	H	H	M	YES	$500	$500	Positioned on a spring system
1	Hanging ceilings	Everywhere	200 m^2	H	H	H		$20/ m^2	$4000	Lacking diagonal wires
5	Water heater	Service room	1	M	M	M		$200	$200	Flammable gases; inflexible piping w/out fastenings
4	Shelving	Storage areas	40 lineal feet	H	M	M		$80	$800	Low priority since no essential items are stored;no anchors present; 2.40m high
6	Medium height partitions	Workstations	20 every 2 m	M	M	M		$602	$1200	Stable level
3	Hanging fluorescent lights	Offices and lobby	50	H	M	M		$50	$2500	Loose connectors from the ceiling
								TOTAL		
L (Low);M (Moderate);H (High)										

Source: FEMA, *Reducing the risks of nonstructural damage:a practical guide.* (FEMA 74 supersedes 1985 edition). Washington, D.C. 1994.

Table 3.5.
Example of assessment of nonstructural components used for the Hospital Nacional Edgardo Rebagliati Martins of the Peruvian Social Security Institute

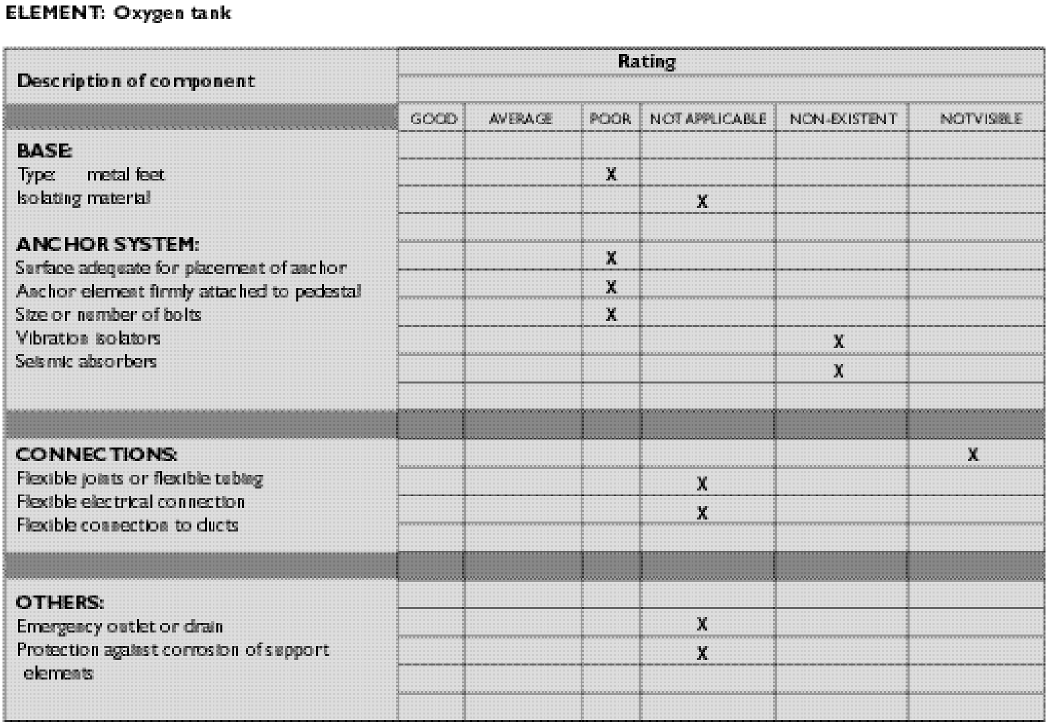
Nonstructural components	Damage level due to unsuitable installation	Consequences and probable damage due to unsuitable protection or installation	Type of risk
Lighting system			
INCANDESCENT FIXTURES: Fixed lightning Hanging fixtures Backet type	From slight to total loss	• In the case of fixed bulbs there are generally no damages • The non-supported hanging systems can collide, becoming inoperative • The hanging systems that run on rails might come off their axis • Possibility of inoperative bulbs	■
Emergency lighting	From slight to total loss	• Falling of the equipment due to non-existent or unsuitable fastening • Breakage of equipment should it fall • Power connection may break	❋ ▲ ■
LAMPS: On furniture Free-standing	From slight to total loss	• Overturning and/or falling • Breakage of the equipment	▲ ■
Ornaments and permanent attachments			
Parapets Cornices Projections Balconies Banisters Gratings Posts Pedestals Veneer Signs	From slight to moderate loss	• Shifting • Falling • Overturning • Breakage • Collapse	❋ ▲ ■
Building joints			
Joint cover Condition Open separation Material	From slight to moderate loss	• Damage to tare weight or walls due to filled construction joint (avoid filling the joint space between walls with works material). • Confusion and panic of the users as they wrongly relate the behavior of the construction joint with the physical collapse of the building. • Separation of the joint sheating (metal, wood, aluminum,copper, bronze, etc.)	■

❋ = Risk to life ■ = Risk of functional loss ▲ = Risk of loss of goods

Source: Bellido Retamozo, J.;García,Enrique et al. *Proyecto de diagnóstico de la vulnerabilidad sísmica de hospitales del Perú. Sección III:Componente no estructural.* Report prepared for PAHO/WHO, ECHO. Lima-Peru,1997.

An example is shown below of the qualitative analysis of the liquid oxygen tank in a hospital. It is clear from this analysis that in its design the possibility of a strong seismic movement was not considered (table 3.6). Apart from being a slender tank that might easily overturn because its center of gravity is relatively high, its supports are not adequately anchored to avoid the sliding and tipping caused by lateral inertial force (photographs 15 and 16).

Table 3.6.
Qualitative analysis of liquid oxygen tank



ELEMENT: Oxygen tank

Description of component	Rating					
	GOOD	AVERAGE	POOR	NOT APPLICABLE	NON-EXISTENT	NOT VISIBLE
BASE:						
Type: metal feet			X			
Isolating material				X		
ANCHOR SYSTEM:						
Surface adequate for placement of anchor			X			
Anchor element firmly attached to pedestal			X			
Size or number of bolts			X			
Vibration isolators					X	
Seismic absorbers					X	
CONNECTIONS:						X
Flexible joints or flexible tubing				X		
Flexible electrical connection				X		
Flexible connection to ducts						
OTHERS:						
Emergency outlet or drain				X		
Protection against corrosion of support elements				X		

Evaluating architectural elements

The architectural elements described below have been shown to be the most sensitive to deformation. Therefore, in order to ensure that the facility can meet the safety level of immediate occupation after an earthquake, it is essential to limit the possibility of structural deformations or to take special precautions regarding these elements. To achieve this, seismic rehabilitation of the structure is required or there must be total independence between the architectural elements and the structural components such as walls, beams and columns.

Nonstructural walls

Nonstructural walls are those made of masonry or other material and are used to divide spaces. They support their own weight and have a very limited capacity to support lateral stresses or to absorb significant structural deformations.

Photograph 15. Side view of the liquid oxygen tank.

In these walls, failure occurs due to cracking and lateral shifting along the cracks. Small cracks caused by slight movement of the load-bearing structure in general are not critical although they do lead to detachments of the covering (paneling, plaster, tiles), which could interfere with the hospital's performance depending on the size of the pieces that come off. Cracks of more then 0.007 millimeters are a sign of loss of support capacity along the edge and therefore, of serious failure of the wall. In general, to meet a safety level for immediate occupation, it must be determined that these cracks do not compromise the wall's shear-resisting capacity and that there are no deformations outside the plan.

Photograph 16. Detail of support connections for liquid oxygen tank.

Information on the lateral deformation capacity of partition walls used in hospitals is shown in table 3.7.

Although the unreinforced masonry infill, or nonstructural walls in general are not considered to be structural, masonry walls provide stiffness to the building until the moment these walls begin to fail due to the interaction with the flexible structure. If these walls fail irregularly, they can cause serious concentrations of stresses in columns and beams that were not foreseen in the design, a situation that can compromise the structure's stability.

Table 3.7.
Lateral deformation capacity (percentage) of partition walls

Panel type	Service status	Last status	Height x width ratio (cm)
Masonry confined with handmade brick	0.125	0.40	240x240
Masonry confined with machine-made brick	0.25	0.70	240x240
Wood covered with sheets of plasterboard	0.70	1.10	240x240
Wood covered with plasterboard and asbestos-cement	0.65	1.00	240x240
Lightweight concrete	0.20	0.70	240x100
Steel frame covered with asbestos-cement	–	0.55	200x100
Steel frame filled with lightweight concrete panels	0.35	0.95	230x97
Foam polystyrene strengthened with steel mesh and coating	0.35	0.80	240x112
Foam polystyrene core covered with asbestos-cement	0.50	0.75	240x120

Service status: Deformation level at which damage affects the partition wall.
Last status: When the damage level of the partition wall requires its repair or replacement.

Source: Astroza, M., V. Aguila and C. Willatt. *Capacidad de deformación lateral de tabiques.* Proceedings of the 7th Chilean Meeting on Seismology and Anti-seismic Engineering, Vol. 1, La Serena, Chile, November 1997.

Facings and finishes

If the heavy covering on the outside of the building partially falls during an earthquake, that is to say, if one side of the building loses a good part of its covering and the other side does not, as well as causing damage to the people or items around the building, an imbalance will occur that will lead to torsion effects to the building (see photograph 17). This torsion may not have been foreseen in the original structural calculations and could result in partial collapse of the building. It is important to emphasize that, after an earthquake, what appears to be significant damage, might only be damage to panelling that does not compromise the hospital's structural stability. However, such damage could cause difficulties in the function of the hospital due to lack of asepsis or obstructions, etc.

PAHO/WHO

Photograph 17. The addition of aesthetic features on buildings can increase their vulnerability in earthquakes.

Seismic-resistant design codes usually include requirements for limiting drift or deformation between stories with the aim of ensuring the protection of the nonstructural elements affixed to the diaphragm. A limit for hospitals included in the ATC-3 code specifies 0.01 times the free height between floors for the design earthquake. However, if there are any doubts about the proposed limit, it is advisable to isolate these nonstructural elements from structural components.

As regards the masonry walls joined to the structure, the isolation should be in conformity with the overall conception of the structure's design. If the structural design does not include these walls as part of the seismic-resistance system, they can cause problems of torsion due to their asymmetrical position or can create "soft stories" when concentrated on only a few floors. Since these are problems commonly presented by this type of wall, it is advisable to isolate them from the structure. Rosenblueth[6] provides several wall isolation diagrams with respect to the diaphragm and to the portico.

In the case of nonstructural walls that do not present problems because of their position in the plan and elevation, it is advisable to consider them in the analysis as part of the seismic-resistant structure. This is very important since the seismic response of the construction as a whole may be very different from that foreseen by the model if the presence of these walls is ignored. In fact, the variation of stiffness in the model leads to different design stresses, both in moderate and intense earthquakes.

Short column

Another architectural problem that has an impact on the structure is the "short column effect" (see photograph 18). Sometimes, particularly during the remodeling of a building, openings in the structure are closed with masonry infill to a certain level, leaving space for windows in the upper part. This confines the lower part of the columns and essentially shortens their effective length. It is known that such "short columns" fail in the case of earthquakes.

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[6] Rosenblueth, E. (ed.), *Design of earthquake-resistant structures*. New York, 1981.

O.D.Cardona

Photograph 18. Short-column effect

Ceilings

Ceilings are nonstructural elements that are sensitive to deformation and acceleration produced by earthquakes. The deformation of the floor slabs can cause horizontal distortion and the deformation of the main structure and the ceiling can lose its support and fall. The seismic behavior of hanging ceilings depends mainly on how the support system responds to seismic movement. The aluminum plate generally performs well when it is correctly attached (suitable wires and supports) and if the adhesive material that joins the plates to the profiles is effective.

Lightweight panels should not be fragile; in other words, they must be able to support deformations without twisting or cracking.

A certain range of deformations in the aluminum plate can cause the massive collapse of ceiling panels (see photograph 19), which poses the threat of possible injuries to the occupants and can cause damage to equipment and block exit routes.

O.D.Cardona

Photograph 19. Damage to ceilings

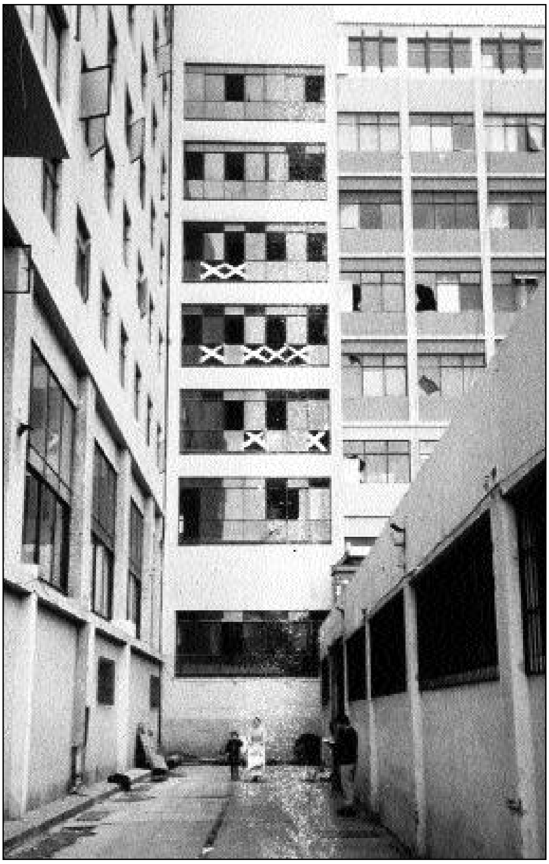
Likewise, care should be taken that the light fixtures, which form part of the ceilings, have an independent support system so that if the ceiling collapses the lighting system can continue functioning.

Windows

The metal window frames attached to the structure or to the nonstructural walls twist and buckle when they are subjected to large deformations, causing the glass to come out of the frame or to break (see photograph 20). This problem is due to several causes:

- The glass has been cut too small for the opening;
- The glass has been cut too large for the opening, leaving little or no margin for it to adjust to deformations in the frame;
- The glass does not fit well in the frame, so that it moves independently of the frame and can break or fall out.

Due to the above, and to the fact that the structure does not have adequate stiffness to restrict lateral deformations and angular distortion of the window openings, it can be expected that in the case of a moderate or intense earthquake a significant number of windowpanes will break.



R. Boroschek

Photograph 20. Broken windows can injure building occupants and obstruct circulation and evacuation routes.

Reducing nonstructural vulnerability

To carry out measures to reduce nonstructural vulnerability, a disaster mitigation plan for the facility must be developed with the involvement of the following professionals: hospital director, chief administrator, head of maintenance, head of clinical and support services and professionals who are experts in applying mitigation measures. It may be appropriate to include other professionals on the team, depending on the type of project being undertaken.

Once a nonstructural element has been identified as a potential threat and its priority established in terms of loss of lives, of property and/or function, the appropriate measures must be adopted to reduce or eliminate the hazard. Twelve applicable mitigation measures, which have been effective in many cases, are listed below.[7]

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[7] FEMA, *Non-structural earthquake hazard mitigation for hospitals and other care facilities* (FEMA IG 370). Washington, D.C., 1989.

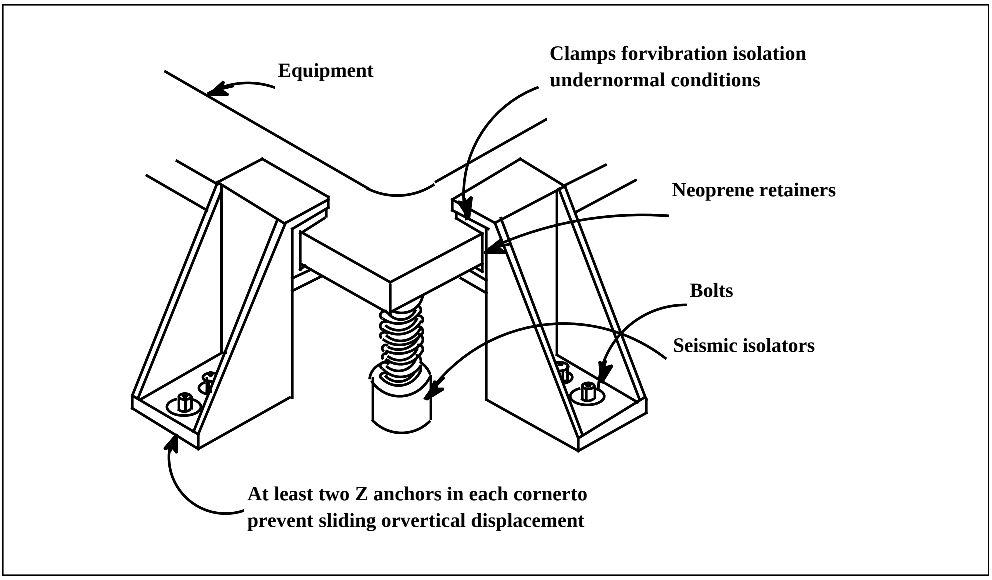
1. Removal
2. Relocation
3. Restricted mobility
4. Anchorage
5. Flexible couplings
6. Supports
7. Substitution
8. Modification
9. Isolation
10. Strengthening
11. Redundancy
12. Rapid response and preparation

Removal is probably the best mitigation option in many cases. An example is a hazardous material that could be spilled, but it could be stored perfectly well outside the premises. Another example would be the use of a very heavy covering in stone or concrete on the outside of the building, which could easily come loose during an earthquake. One solution would be better fastenings or the use of stronger supports, but the most effective solution would be removal and replacement.

Relocation would reduce danger in many cases. For example, a very heavy object on top of a shelf could fall and seriously injure someone, as well as breaking and causing economic losses. If it is relocated to a floor-level shelf it would not represent any danger to human lives or to property.

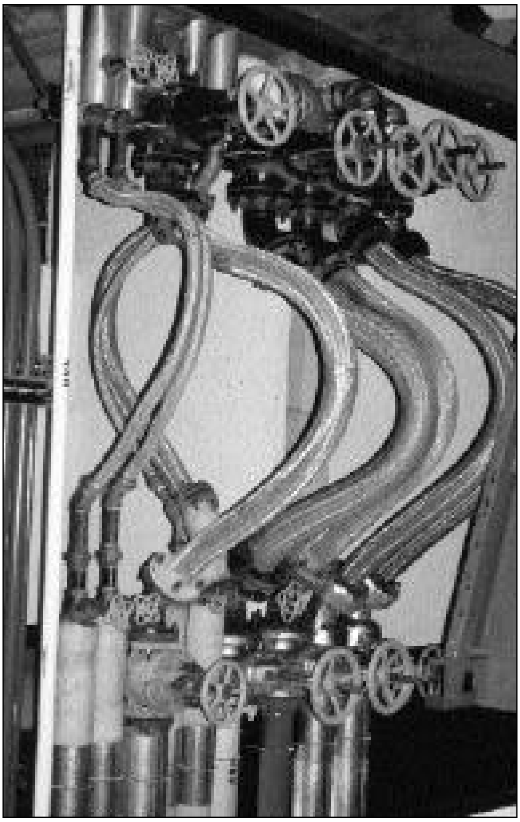
Restricted mobility for certain objects such as gas cylinders and power generators is a good measure. It does not matter if the cylinders shift as long as they do not fall and break their valves. Sometimes back-up power generators are mounted on springs to reduce the noise and vibrations when they are working, but these springs would amplify ground motion. Therefore, restraining supports or chains should be placed around the springs to keep the generator from shifting or being knocked off its stand (see figure 3.3).

Figure 3.3.
Vibration isolation clamps

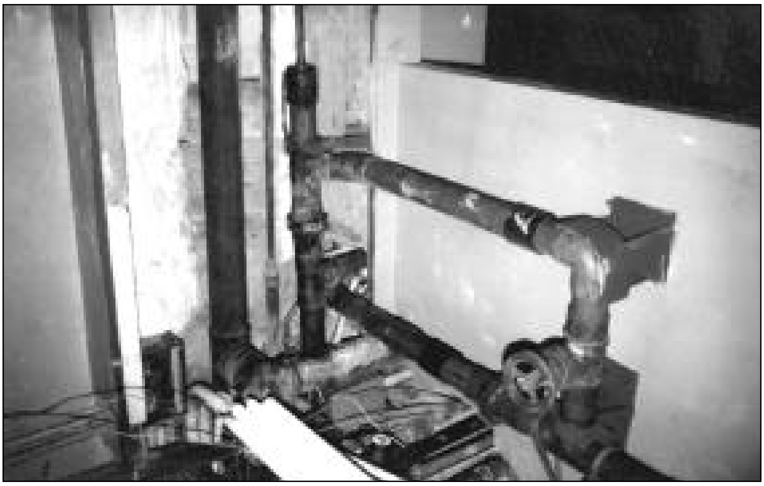


Anchorage is the most widely used precaution. It is a good idea to use bolts, cables or other materials to prevent valuable or large components from falling or sliding. The heavier the object, the more likely it is that it will move due to the forces produced by an earthquake. A good example is a water heater, of which there will probably be several in a hospital. They are heavy and can easily fall and break a water main. The simple solution is to use metal straps to fasten the lower and upper parts of the heater against a firm wall or another support.

Flexible couplings sometimes are used between buildings and outside tanks, between separate parts of the same building, and between buildings (see photographs 21 and 22). They are used because the separate objects each move independently in response to an earthquake: some move quickly, others slowly. If there is a tank outside the building with a rigid connection pipe that joins them together, the tank will vibrate at frequencies, directions and amplitudes that are different to those of the building, causing the pipe to break. A flexible pipe between the two would prevent ruptures of this kind (see figure 3.4) .

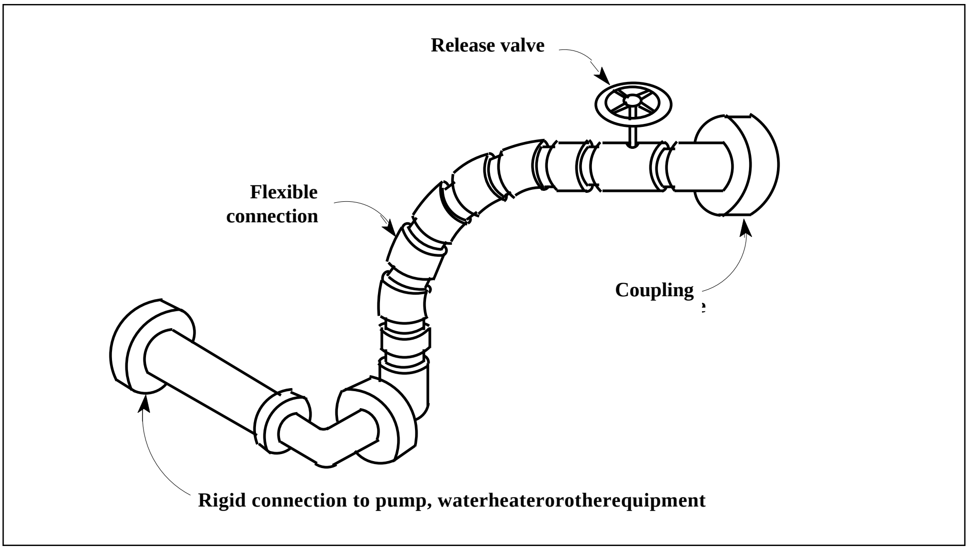

OPS/OMS, C. Osorio

Photograph 21. The use of flexible piping in critical areas such as between buildings and equipment helps to prevent breakage


O.D.Cardona

Photograph 22. Rigid piping

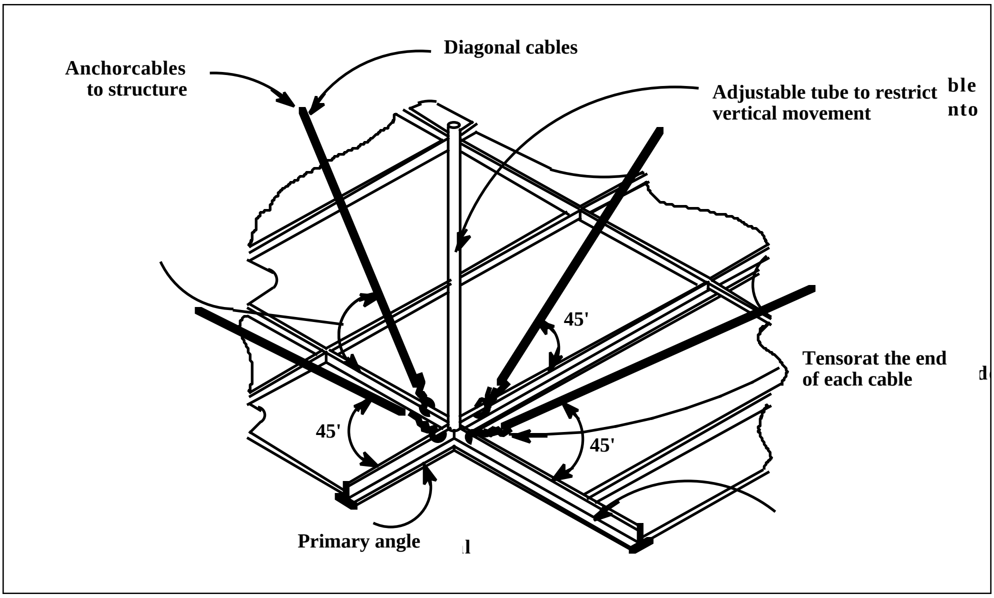
Figure 3.4.
Flexible fitting and connection



Federal Emergency Management Ageny

Supports are suitable in many cases. For example, ceilings are usually hung from cables that only withstand the force of gravity. When subjecting them to the horizontal stresses and torsion of an earthquake, they easily fall (figure 3.5). They can cause serious injury to the people who are underneath them and obstruct evacuation routes.

Figure 3.5.
Supports for ceiling



Substitution by something that does not represent a seismic hazard is appropriate in some situations. For example, a heavy tiled roof does not only make the roof of a building heavy, it is also more susceptible to the movement of an earthquake. The individual tiles tend to come off, creating a hazard for people and for objects. One solution would be to change it for a lighter, safer roofing material.

Modification is a possible solution for an object that represents a seismic hazard. For example, earth movements twist and distort a building, possibly causing the rigid glass in the windows to shatter and launch sharp glass splinters onto the occupants and the passers-by around the hospital. Rolls of transparent adhesive plastic may be used to cover the inside surfaces and prevent them from shattering and threatening those inside. The plastic is invisible and reduces the likelihood of a glass window causing injuries.

Isolation is useful for small, loose objects. For example, if side panels are placed on open shelves or doors with latches on the cabinets, their contents will be isolated and probably will not be thrown around if an earthquake were to occur.

Reinforcement is feasible in many cases. For example, an unreinforced infill wall or a chimney may be strengthened, without great expense, by covering the surface with wire mesh and cementing it.

Redundancy or duplication of items is advisable. Emergency response plans that call for additional supplies are a good idea. It is possible to store extra amounts of certain products, providing a certain level of independence from external supply which could be interrupted in the case of earthquakes.

Rapid response and repair is a mitigation measure used on large oil pipelines. Sometimes it is not possible to do something to prevent the rupture of a pipeline in a given place, therefore spare parts are stored nearby and arrangements are made to enter the area quickly in case a pipe breaks during an earthquake. A hospital should have spare plumbing, power and other components on hand, together with the suitable tools, so that if something is damaged repairs can be easily made. For example, during an earthquake the water pipes may break; it may be impossible to take prior measures to totally eliminate this risk, but it should be possible to ensure that everything necessary for quick repair is at hand. With prior earthquake planning it is possible to save the enormous costs of water damage with a minimum investment in a few articles.

These general measures are applicable to almost all situations. However, in many cases, it is enough to be creative and to devise one's own way of mitigating the effects of disasters.

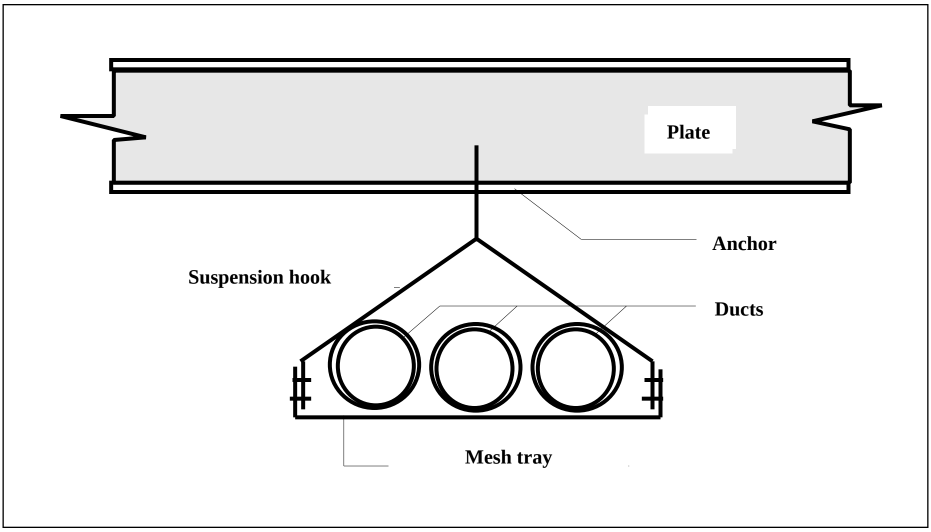
Damage mitigation in basic services

The objective of applying mitigation measures in basic services is to ensure that the hospital has a guaranteed, continuous supply of key utilities such as water and power. This would include having, for example, adequately sized reservoirs to maintain water supply and a power plant so that it is not dependent on municipal or other networks.

Installations for the supply of water, clinical gases, steam and power are vulnerable and in most cases they are located above the false ceilings. If special care is taken during construction to install these networks by suspending them, for example, from mesh plates and anchoring special supports to the plates, they can be prevented from falling or being disconnected in the case of an earthquake. Another advantage provided by mesh support is to extend the rigid network, combined with stretches of flexible networks every certain number of meters, thereby avoiding breakage of the network.[8]

The same solution should be applied to vertical ducts, which, if properly located with sufficient space, can absorb seismic movements. It is also important to provide for doors in these ducts to allow access for inspections and maintenance to the system (see figure 3.6).

Figure 3.6.
Detail of the hanging duct



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A solution that has been used recently is to leave all mechanical installations on the façades in full view. This facilitates not only normal inspection of the installations but also easy access for repair in case of damage. It would also be advisable in individual rooms or other areas to plan the placement of installations in a way that would allow the number of beds to be increased if the situation demanded it. This would increase the response capacity in emergency situations.

Hot water and steam in kitchen areas are potential hazards and must be subjected to ongoing inspection by maintenance personnel to verify, among other things, that conduits are securely anchored and that there are no possibilities of leakage.

A large part of the equipment in a hospital requires connections to electrical or mechanical systems. In the event of an earthquake it is necessary to carry out an immediate inspection. Although the equipment may be appropriately installed, there might have been enough movement to alter the rigid connections. This alteration can endanger lives of the patients if essential equipment connected to the water, steam or gas networks malfunctions. The following may be noted as possible solutions to this situation:

- Flexible hose connections;
- Connections with rotating movement;
- Automatic shut-off valves.

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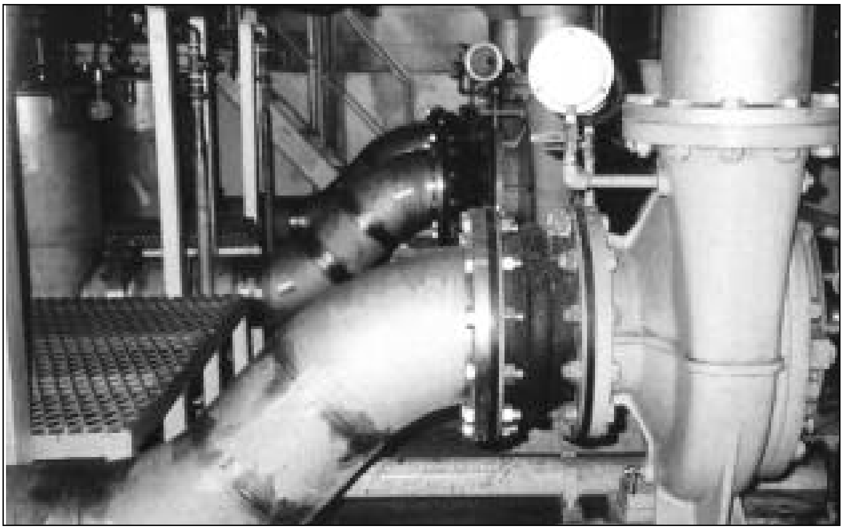
[8] FEMA, *Reducing the risks of nonstructural earthquake damage: a practical guide.* (FEMA 74 Supersedes 1985 Edition) Washington 1994.

Emergency power plants are heavy objects; the heavier they are, the greater the possibility that they will move. Mounting this type of equipment on springs amplifies the movement in an earthquake, which must be taken into account when designing constraining measures. The movement of a generator can block entrances, shift structural components or sever the power and fuel supply lines. Therefore, the connections and installation must have special treatment. Flexible connections are recommended.

Among the recommendations for protecting the emergency power plant, the following are worth mentioning:

- The plant should be anchored or restrained in such a way that it can not move or slide;
- The fuel source must be available during and after the earthquake;
- The start-up batteries or automatic start-up system must be in perfect working order.



O.D.Cardona

Photograph 23. Piping with flexible connections

Fuel to operate the emergency plant must be continuously available, regardless of the damage that is produced by any movement or accident. It is also necessary to make sure that the spare batteries are stored on properly braced shelves so that they will not fall.

Communications, both internal and external, must continue to function at all times.In emergency situations portable radio systems, loudspeakers, etc. must be on hand to organize both the personnel and the users of the building. Communications are also essential to maintain contact with the outside world, with referral hospitals or with the patients' families.

Some equipment necessary in hospitals is hung from the ceilings or the floor slabs, as in the case of overhead lamps in operating theaters and obstetrics, x-ray units that need a certain amperage, some equipment in exercise therapy rooms, and exhaust hoods in kitchens and some laboratories. Recommendations and specifications for securing these items supplied by the manufacturers generally specify beams and special bolts for hanging the equipment.

It is also recommended that furniture containing medicines, bottles and containers of different types have a railing in front of each shelf to prevent the stored items from falling or spilling, causing danger or obstacles for the users.

Box 3.1 Assessing nonstructural vulnerability in Colombia

Bucaramanga is a city located in northeastern Colombia,in an area of high seismic risk.Its main health facility, the Hospital Ramón González Valencia,is a massive, twelve-story building designed and built at the beginning of the 1950s on a frame structure with isolated footings at a depth of two meters,due to the fact that the soil has a capacity that exceeds 4 kg/cm2. Due to its age and its structural configuration,it may be concluded that this type of building is significantly vulnerable to earthquakes.This is not the result of lack of care in its design and construction,but rather because in 1950 knowledge was lacking about seismic hazards in the area and structural behavior of this type of building when faced with earthquakes.

For several years, the authorities of the hospital and of the region tried to identify local, regional and national resources to carry out a seismic structural vulnerability assessment, without positive results. In 1996, the Ministry of Health finally managed to obtain some financing for nonstructural and functional vulnerability studies.These were the first formal nonstructural vulnerability assessments carried out in the country and paved the way for carrying out other studies in hospitals in Bogotá and Manizales.

One of the most important results of the nonstructural study was the confirmation of the need to assess the structural response of the building in strong earthquakes.Due to the flexibility of the structure and its potentially poor performance in the case of strong seismic events,it was concluded,using simplified,qualitative methods,that the deformations that the structure could undergo would cause serious damage to nonstructural elements, be they equipment,installations or architectural components.The study indicated that while addressing nonstructural and functional vulnerability would be highly beneficial, structural damage would compromise the operation of the hospital.In 1997, after overcoming several bureaucratic obstacles, resources for the structural seismic vulnerability assessment and the retrofitting design were finally achieved.

Source: Cardona, O.D.,Análisis de vulnerabilidad no estructural y funcional del Hospital Ramón González Valencia de Bucaramanga,Consultant contract 972-96,Ministry of Health,Bogotá,1997.

Damage mitigation in architectural elements

The selection of the covering materials and finishes in a hospital is important not only for reasons of aesthetics and durability, but also for considerations about disaster mitigation. It is not enough for the hospital not to fail structurally. Its finishes, walls, doors, windows, ceilings, and so on must remain in place, so that they do not become a threat to human life or hinder the movements of the patients, medical and paramedical personnel and others who are inside or who visit the building at the moment of a disaster.

Ceilings are usually hung from the structure or floor slab, and in hospitals, they become an almost unavoidable system since the space between the floor slab and ceiling houses the supply networks for water, light, clinical gases, communications, etc. The specifications for the ceilings must meet aseptic standards and be built with non-flammable, lightweight materials that are capable of resisting movement.

Sometimes aesthetic aspects must be sacrificed to satisfy mitigation needs, as happens with roofs, particularly in hospital buildings with horizontal design. A tiled roof is very heavy, a situation that makes it more vulnerable to earthquakes. The tiles can also fall and injure people nearby.

The use of covering materials on the façade is very common; these can come off in the case of earthquakes. To mitigate this aspect it is advisable to use structural materials on the façade, such as open-faced brick or other materials that have not presented problems in past earthquakes.

Very large surface areas of glass constitute a danger in the case of earthquakes. Designers can specify safety glass or reduce the size of panes.

There is a tendency to use prefabricated elements for railings on balconies. In most cases, sufficient fastenings are not specified for them to form an integral part of the building, increasing the likelihood of their becoming detached. The same occurs when designing banisters, handrails, etc.; these elements must be firmly anchored to the structure so that there is no risk of their coming off.

Some designers choose to place flower boxes on the façades thereby increasing loads. This type of element should not be used in hospitals.

Large canopies often are used in solarium areas, which in many cases are finished with glass and can be extremely dangerous. Although acrylic or plexiglass panels are not foolproof, they may be used with a greater level of confidence to prevent the risk of accidents when tremors occur and elements used in the canopy come off.

To the extent possible, furniture should be placed along walls, and anchored, if possible, on both the sides and back.

The decision to isolate masonry elements must be done with care. They must be suitably anchored to compensate for their independence and to prevent collapse (see photograph 24). In general, the structure's masonry should be isolated in the following cases:

- When its position in the plan tends to cause strong eccentricities in stiffness and, due to this, significant torsion;
- When it tends to produce excessive stiffness on one or several stories in relation to the others, converting them into "soft stories".

J. Grases

Photograph 24. Walls destroyed due to flexibility of the structure

Mitigating damage to equipment and furnishings

Most hospital equipment and supplies are essential for the functioning of the facility and for protecting the lives of its occupants, and yet they can represent a danger in case of an earthquake.[9] Some of the equipment and furnishings that should be included in vulnerability assessments are presented in table 3.8. The selection has been made considering their importance both for life support of patients and for providing emergency care after an earthquake. Another factor is their cost.

Table 3.8.
Equipment to be assessed for vulnerability

Anesthesia machine with ventilator	Industrial freezer
Autoclave	Infusion pump
Automatic cell counter	Kitchen equipment
Bilirubin meter	Laparoscopy equipment
Biochemical analyzer	Lontofor equipment
Blood bank freezer	Microcentrifuge
Boilers	Microscopes
CT scanner	Operating table
Centrifuges	Osmometers
Kitchen equipment	Oxygen concentrator
Culture incubator	Oxygen cryogenic tank
Ovens	Oxygen cylinder
Dryers	Pavilion lamp
Electric photometer	Plate developers
Electrocardiogram defibrillator monitor	Plate processing equipment
Electrodiathermy	Power generator
Electrostimulator	Pulmonary function analyzer
Elevator and/or freight elevator	Pulse oxymeter
ELISA analyzer	Respirators
Ethylene oxide sterilizer	Sterile and non-sterile material stores
Flame photometer	Suction machine or pump
Freezer	Telephone switchboard
Gamma chambers	Ultrasound
Gas analyzer	Urine analyzer
Gas cookers	Vital signs monitors
Geiger counter	Washing machines
Hemodialysis machines	Water pump system
Image intensifier	X-ray equipment
Incubator	

Source: Boroschek R.,Astroza M.,Osorio C.,Kausel E. "*Análisis de vulnerabilidad y preparativos para enfrentar desastres naturales en hospitales en Chile*". Universidad de Chile, Study conducted for PAHO/WHO – ECHO, Santiago, Chile, 1996.

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[9] FEMA, Seismic protection provisions for furniture, equipment, and supplies for Veterans Administration hospitals, Washington, D.C., 1987.

Below are some special considerations for these equipment and installations, as well as for other elements:

Essential diagnostic equipment:

Phonendoscopes, tensiometers, thermometers, otoscopes, ophthalmoscopes, reflex hammers and flashlights should always be available for physicians, paramedics, and administrative staff.

Mobile carts:

Carts used to move special equipment for crisis intervention are particularly important for saving lives and storing supplies. They are found in all patient care areas. Objects must be secured to the trolley. When not in use the trolleys must have their brakes on and be parked against dividing walls.

Respirators and suction equipment:

This equipment should be secured in such a way that they do not become disconnected from the patients.

Hazardous substances:

Many of the products used in a hospital are classified as hazardous. Storage shelves containing medicines or chemicals, if overturned, can constitute a hazard by virtue of their toxicity, both in liquid and in gas form. On many occasions fires start by chemical action, overturned gas cylinders or ruptures in gas supply lines.

Heavy articles:

Heavy articles such as televisions on high shelves near the beds, in waiting rooms or meeting spaces can pose a threat if they fall. Some specialized pieces such as X-ray equipment, ceiling lamps, sub-stations, etc. could be damaged if not firmly fastened.

Filing cabinets:

In most cases they store clinical notes and a large amount of information necessary for patient treatment. They must be secured to the floors and walls to prevent them from tipping over.

Computers:

Much of a hospital’s general information is contained on computers; they must be well secured to desks to prevent them from falling and losing their function. Computer services must take the recommendations made for networks into account, and computers should be backed up by the emergency power plant.

Refrigerators:

It is particularly important for the blood bank refrigerator to maintain continuous cooling, and it should be connected to the emergency power supply. If this is not the case the blood reserve can be lost along with medicines, food and other supplies that require refrigeration and that are necessary in emergency situations.

Nuclear medicine:

This sector presents particularly hazardous situations, given the type of equipment and materials used.

Kitchen area:

During emergencies, food service must be guaranteed; therefore all its equipment such as cooking pots, ovens, stoves, exhaust hoods, grinders, industrial blenders, thermal trolley, etc., must be sufficiently anchored to tables, walls or ceilings to ensure that they continue to function and do not fall and cause injuries.

Gas plant:

It has been observed that inappropriate location of this service may constitute a major hazard in the case of an earthquake and proper safety standards must be applied in this regard. The plant must be sufficiently ventilated and preferably located outside the building block. The plant should face areas that are unoccupied by people in the event of an explosion.

Gas cylinders are also used by some hospitals and are found throughout the building, mainly in support areas. Some contain toxic gases and others flammable gases. They must be isolated to avoid injury to the personnel, to the patients or damage to the cylinders themselves.

Maintenance workshops:

They are very important both in normal situations and in emergencies, since they are used for the repair of a large number of electrical, health and plumbing installations, etc., that are necessary in the event that the building is damaged.

It would be practically impossible to make a complete list of all the elements involved in the performance of a hospital. Therefore, in applying disaster mitigation measures common sense must be used at each step, such as for example, avoiding placing equipment and other items above patients, staff and transit areas in order to prevent them causing serious damage if they shift or fall.

The preparation of a complete assessment for mitigating seismic risk or another type of disaster is a complex task. Consequently, it is more a matter of raising issues that can be dealt with more thoroughly over time. Each person or organization can add its own procedures, adding new solutions to those already implemented, so long as priorities are established, since it is almost impossible to do everything that needs doing. Any advance represents an important step toward decreasing risk factors and the possibility of losing hospital functions when they are most needed.

In general, it is possible to divide mitigation recommendations into two categories:

- Those that are easy to implement and should be carried out by the hospital’s maintenance staff or by contractors.
- Those that require consultation with specialists and capital, such as costly modifications or new constructions to be implemented in the medium or the long term.

In many cases,the implementation of mitigation measures is the responsibility of the maintenance staff, which can be an advantage given their knowledge of the facility and the possibility of carrying out periodic inspections of the mitigation measures adopted. In fact, the improvement of existing buildings and structures can be carried out during routine repairs and maintenance.

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Chapter 4
Administrative and Organizational Vulnerability

Background

Of all the elements that interact in the day-to-day operations of a hospital, the administrative and organizational aspects are among the most important in ensuring that disaster prevention and mitigation measures are adopted before a disaster strikes, so that the hospital can continue to function after an earthquake or other catastrophic event.

Administrative and organizational vulnerability to emergencies and disasters can be analyzed at two different levels. The macro level involves studying the resolution capacity of health facilities, which is based on currently popular concepts of health services modernization and decentralization. This type of analysis is ambitious: its final objective is the implementation of a total quality management policy for health services (see box 4.1). Continually improving the quality of a health facility's services automatically brings about improvements in the structural, nonstructural, and administrative and organizational conditions of day-to-day operations, leading to a hospital that performs more effectively, as a whole, in the event of an emergency or disaster. However, such an analysis lies beyond the scope of this book.

This chapter addresses the micro-level, which normally focuses only on those aspects relevant to a particular health establishment. However, it is possible to draw on the information available from several health facilities, to carry out a micro-level analysis of the administrative and organizational vulnerability of a fairly typical hospital. This includes those operational aspects that might have a negative impact on its ability to provide its services both in normal and in external or internal emergency conditions, as we will see in greater detail below. In order to do this, it is necessary to examine the activities carried out in the different departments of a hospital, their interactions, the availability of basic public services, and the modifications required in the event of an emergency.

Similarly, we will perform a critical review of a typical hospital emergency plan, seen as another administrative and organizational tool, in order to identify its possible weaknesses and underscore the useful components related to guaranteeing the functionality of existing services. It is important to stress that a hospital emergency plan, no matter how well crafted, will be useless if the building suffers serious damage to its physical infrastructure. Accordingly, this analysis is based on the assumption that structural and nonstructural deficiencies have been corrected or, if this has not yet been accomplished, that they have at least been identified and the emergency plan has taken them into account.

Box 4.1. Towards total quality in health care: the continual quality improvement process

The Continual Quality Improvement Process (CQIP) is a new managerial approach that is being introduced in health care programs worldwide.* A CQIP is based on the assumption that many organizational problems result from inadequate systems and processes, rather than individual mistakes. A CQIP encourages the staff at all levels to work as a team, take advantage of collective experience and skills, analyze processes and systems, use available information to identify the nature and magnitude of each problem, and design and execute actions that improve services. Quality is continuously reviewed and incorporated into the working process. Improvements in all functions are carried out gradually and continuously (proactively), and staff members are encouraged to take the initiative, quashing the myth that quality is expensive.

The state of California, in the United States, has very precise terms of reference for contracting preliminary studies and the implementation of CQIP in health services. These include reviewing processes in clinical and non-clinical services, including emergency care, family planning and health education. A CQIP must be steered by a committee that includes the medical director of each health facility, doctors and health personnel, administrators and technicians. CQIP studies must reflect the needs of the population based on age and disease categories.

* Department of Health Services of the State of California. Quality improvement system, 1992.

Note: For a more detailed definition and description of a CQIP program, see *Actualidad gerencial en planificación familiar: estrategias para el mejoramiento de los programas y servicios*, Vol. II, N° 1, 1993.

In the event of a disaster, a hospital must be able to continue caring for its inpatients while treating victims of the event, safeguarding all the while the lives and health of its personnel. For this to happen, the staff must be deployed effectively and know exactly how to respond to such a situation. The building and its equipment, supplies and lifelines must remain operational. Most hospital authorities recognize this fact, which is why they have established formal disaster mitigation plans.

However, most of these plans fail to provide administrative and organizational alternatives in the event of severe damage to the facilities. The issue has received little attention. This is worrisome, particularly in the many locations throughout the Americas where the population only has ready access to one hospital that, if rendered inoperative, could lead to a severe health crisis.

A systematic approach, which takes into account the fluid movement of staff, equipment and supplies in a safe environment during normal operations, is vital if an effective response to disasters is to be in place. This underscores the critical nature and interdependence of the various processes, buildings, and equipment. Deficiencies in any of these areas can plunge a hospital into a crisis.

i) *Processes*: They mostly have to do with the movements of people, equipment and supplies. They also include routine administrative processes such as hiring, acquisitions, human resource management, and the flow of patients through the various clinical and support service areas of the hospital.

ii) *Buildings*: Experience has shown that the design and construction of hospital buildings, as well as their future expansion and remodeling, their everyday operations and maintenance, must be safety-oriented to protect certain critical hospital operations such as emergency care, diagnosis and treatment, surgery, pharmaceutical supplies and food storage, sterilization, patient registration, reservations, or any other areas the institution considers a high priority.

In hospital design, emphasis must be placed on the optimal use of space and the configuration of the services provided, so that the different departments and activities can mesh together with the greatest possible efficiency and the lowest vulnerability. Many facilities have suffered a functional collapse as a result of simple omissions during their design, which could have been easily corrected or addressed at a marginal cost during construction or retrofitting.

iii) *Equipment*: Regular inspections and the proper maintenance can ensure that key and often costly hospital equipment can remain in good working order.

As discussed earlier, it is the duty of the authorities to assess the hospital's vulnerability to natural phenomena and obtain precise estimates of existing risk levels. Once the analysis is complete, the information gathered should be used to determine what level of risk is acceptable. In the case of administrative and organizational vulnerability, the analysis can start with a visual inspection of the facilities and the drafting of a preliminary assessment report identifying key areas that demand attention, alongside a study of administrative procedures, their critical points, and their flexibility in emergency situations.

Administrative aspects

The first aspects that must be evaluated are the administrative procedures related to infrastructure, including the resources that are supplied by public utility networks and on which its function depends, such as communications and information systems, water-supply and sewerage systems, and power supply.

The water-supply system generally includes pumping stations, water treatment plants, and underground mains and other pipes. It may suffer interruptions due to pump failure or, more frequently, pipe ruptures. Hospitals must therefore incorporate water storage tanks into the daily water supply system to ensure that clean water will be available in the event of an emergency.

The power supply system includes generators, high-tension lines, and above-ground substations and equipment. Transformers and porcelain insulators are the weakest points. Health facilities therefore have good reasons to procure emergency generators that can start supplying power at any moment.

During an earthquake, the vulnerability of water, sewerage, gas and fuel pipes depends on their resistance and flexibility. A high degree of flexibility can prevent the rupture of pipes during a moderate earthquake. Differential settlements can be compensated so that ground displacement does not necessarily lead to a rupture. Special attention must be paid to connections entering the building.

For the analysis of administrative procedures, the starting point must be the spatial-administrative relationships within the hospital and with its environment, including special agreements with public utility companies and suppliers in general. The following supplies and lifelines must be taken into account:

- **Water, power and natural gas (if there is a public network)**: Utility company involved; description of the service; location and general state of the main and secondary pipes; normal working conditions; description, general state and location of the main or incoming pipe; and alternative source of supply in the event of the main system failing.

- **Communications**: Service provider; description, general state and location of the link-up; number of lines extensions and expansion capacity; and alternative communications systems through VHF/FM or other frequencies.
- **Roadway system**: Capacity and general state of the main access routes, traffic patterns under normal and critical conditions, and pedestrian routes.

If it is discovered that external public utility networks are intrinsically vulnerable, hospital authorities must demand that utilities assess the vulnerability of external lifelines as part of an integrated local or national vulnerability reduction program. For instance, they must ensure that transformer poles or water mains be reinforced.

The community's Local Emergency Committee must also make sure that the various actors play the role expected of them in the emergency plan in order to guarantee the supply of basic public services to the hospital. This would include cordoning off nearby roads to ease the access of emergency vehicles and establishing security procedures to control access to the facilities. One of the functions of a Local Emergency Committee must be to ensure that lifelines remain operational or are quickly up and running again if disrupted. The institutional members of the Operational Committee must collaborate in key activities such as the provision of first aid, the prompt transport of the injured by ambulances and other vehicles, and public order in general.

Spatial distribution

To carry out an analysis of the internal and external spatial distribution of a hospital vis-à-vis its operation, both in normal and emergency situations, the following steps must be taken:

1. Develop an assessment model, based on current guidelines and existing models, and on desirable performance patterns. Assign priorities to the spaces that need to be assessed on the basis of the clinical or support services considered indispensable for emergency response.
2. Have the medical staff and participating architects and engineers review the building plans, the building inspection process, and the location of each relevant area, and establish the functional relations between them that must be reflected in the spatial arrangements of the various medical and support areas.
3. Analyze and evaluate the internal and external spatial organization of the hospital and compare with current standards and best practices.
4. Make recommendations on how to improve the functionality of deficient aspects.

Spatial distribution must be assessed on the basis of normal operations and their ability to respond to the massive need for emergency services, as well as the ability of other spaces to be adapted quickly to support the above services. An example of the physical and operational interdependency between services is included in figure 4.1.[1]

To reduce administrative and organizational vulnerability, recommendations must be made concerning efficient spatial distribution and interaction, once again both in normal conditions and when the number of victims exceeds the everyday capacity of the hospital. These recommendations must include solutions to help improve the internal and external functionality of the services provided by the hospital and their interactions in the event of an emergency.

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[1] A similar chart may be found in Isaza, Pablo and Carlos Santana, *Guías de diseño hospitalario para América Latina*. PAHO Health Services Development Program, Series N° 61, 1991.

The issues to be considered include the following:

- *Access to the hospital complex*: Vehicle and pedestrian access; access by the staff and the public; auxiliary pedestrian access (exclusively for hospital and services staff); and air access, if available, in the form of a heliport or nearby runway.
- *Internal spatial relations (general hospital ground plan)*: Division between critical and complementary functional areas; internal and external spatial organization; spatial capacity to provide emergency response services without ignoring regular functions.

Figure 4.1.
Hospital services interrelationship matrix

	Administration	Training	Outpatient Care	Radiology	Clinical Laboratory	Pathological Anatomy	Physiotherapy	Emergency Care	Surgery	Obstetrics	Sterilization	Intensive Care	Hospital Admissions	Staff Dressing Rooms	Kitchen	Maintenance	Machine Room	Laundry Room
Training	●																	
Outpatient Care	●	●																
Radiology	●	●	■															
Clinical Laboratory	●	●	■	▲														
Pathological Anatomy	●	●	▲	✚	●													
Physiotherapy	●	●	●	■	✚	✚												
Emergency Services	●	●	●	■	■	■	✚											
Surgery	●	●	●	■	■	■	✚	■										
Obstetrics	●	●	●	■	■	■	✚	■	■									
Sterilization	●	●	●	▲	▲	▲	✚	■	■	■								
Intensive Care	●	●	●	■	■	■	✚	■	■	■	●							
Admissions	●	●	✚	●	●	■	●	■	■	■	■	■						
Staff Dressing Rooms	●	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲					
Kitchen	▲	✚	✚	▲	▲	▲	▲	▲	▲	▲	▲	▲	■	●				
Maintenance	▲	✚	✚	▲	▲	▲	▲	▲	▲	▲	●	▲	▲	●	●			
Machine Room	▲	✚	✚	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	●	■	■		
Laundry Rooms	▲	✚	✚	▲	▲	▲	▲	▲	▲	▲	●	▲	■	●	■	■	■	
General Storage	▲	✚	●	▲	●	▲	▲	▲	▲	▲	▲	▲	●	■	▲	●	●	■

■ Key relationship
● Direct relationship
▲ Indirect relationship
✚ No relationship

The hospital's functionality, depending on the kinds of parameters used to measure it, can be rated as follows:

Good: The parameter under review satisfactorily meets current local standards in disaster reduction; there is no need to modify it.

Average: The parameter under review satisfies local standards only moderately; a minor modification could improve performance significantly.

Poor: The parameter under review does not meet local standards; it must be modified substantially to resolve this deficiency.

An example of functional-spatial assessment: the Ramón González Valencia Hospital in Bucaramanga, Colombia		
Relationship between the hospital and its environment	Good	The hospital is surrounded by a major roadway, Quebrada Seca Ave.; a main road, Carrera 33; and two secondary roads (Carrera 32 and Calle 32) that are wide and permit easy access both for pedestrians and drivers from the neighborhoods served by this hospital. It is close to a military camp (the Caldas Batallion), with a heliport that can be used during a major emergency.
Access		
Vehicle access 1 (V-1) to the main parking lot of the hospital complex, from Carrera 33, for employees only	Good	Cars can come in and out at the same time without hindrance, due to the width of V-1. V-1 can also be used to deliver patients or emergency supplies to the main building entrance without having to go through the parking lot. It is a controlled access, since only employee vehicles are allowed in.
Vehicle access 2 (V-2), from Carrera 32, to provide maintenance to power plant and storage tanks	Good	Fluid access by maintenance vehicles. Only maintenance vehicles allowed.
Vehicle access 3 (V-3), from Carrera 32, to the Emergency Care Unit, the Health Faculty and the Morgue	Average	While it provides access to the Emergency Care Unit, the Morgue and the Triage Area (formerly the Emergency Unit parking area), vehicle movements are obstructed when ambulances and private cars are delivering patients to the Emergency Unit. Moreover, it is not easy to turn around and get out.

Access		
Pedestrian access 1 (P-1) to the Main Hall	Good	Provides access to the public, ambulatory patients, visitors and staff from the square in front of the Main Hall.The Main Hall provides access to the Administration Dept., internal access to other hospital areas, and vertical access to the upper floors of the building.
Pedestrian Access 2 (P-2) to Outpatient Services	Good	It is an independent,direct access from the public square to the main lobby or entrance hall of the hospital.Due to its location,it facilitates the arrival of ambulatory patients,visitors and the general public.
Pedestrian Access 3 (P-3) to the Blood Bank, ground floor	Good	It is an independent,direct access from the public square to the main lobby. People who use this service are not necessarily hospital patients, so having an entrance that is completely independent from the other hospital areas is convenient.
Adjacent Structures		
Adjacent Buildings (1)	Good	The main building is made up of volumes of different heights and geometric configurations. However, no structurally independent modules were identified that might act as adjacent structures and produce a knock-on effect.
Adjacent Buildings (2)	Average	In the case of the other buildings in the hospital complex,no adjacencies were identified. However, due to the proximity of the Health Faculty building to the Emergency Care Area and the Morgue, any falling debris due to structural or nonstructural damage might block access to these units.

Source:Cardona, O.D.,et al. *Informe final del proyecto vulnerabilidad funcional y no-estructural del Hospital Ramón González Valencia,* Colombia,1997.

Organizational aspects

Among organizational aspects, many of the problems faced by a hospital in its day-to-day operations are caused by deficiencies in its preventive maintenance programs, or even by the lack of such programs. Ordinarily, this is not due to a lack of administrative will to implement maintenance standards, but to a lack of human and financial resources to carry out this task. In addition, lack of planning when expanding or modifying the physical facilities can lead to disorganized growth, which in turn can affect operations negatively, interrupting or slowing down some services and causing frustration among users.

It is important to stress that the disaster response elements outlined in this chapter must be seen as part of a broader, systematic disaster mitigation and prevention plan for the hospital.

A hospital can face two kinds of emergencies: external or internal.

- An external emergency, for our purposes, can be the result of a natural disaster that has struck the community, requiring the hospital to remain minimally operational (i.e., with little or easily manageable structural or nonstructural damage), or it can be related to an enormous increase in the demand of some service, frequently emergency care, due to a specific external factor such as an epidemic or a massive traffic accident in the vicinity.
- An internal emergency takes place when a given set of circumstances leads to the functional collapse of one or more of the services provided by the hospital. These circumstances can include a fire (an operational failure) or the sudden unavailability of lifelines or indispensable equipment due to, for instance, an explosion, or even something as simple as lack of preventive maintenance.

In some cases, both types of emergency may coincide.

Regardless of the type of emergency, the institution must be capable of resolving the technical deficiencies that may arise, in the shortest possible time, and reorienting the necessary human and logistical resources towards the services that most urgently require them. It is also necessary to plan in advance, with the support of public service providers such as firefighters, paramedics, civil defense officials, and transit authorities, in order to establish cooperation and coordination agreements. This might require setting up a formal emergency response network at the local level, including a system of referral facilities that can accommodate an overflow of emergency patients or that might transfer patients presenting injuries of a certain level of complexity.

All these inter-institutional mechanisms must be taken into account in the hospital's disaster mitigation and prevention plan, on the basis of the vulnerability of the structure, its equipment, and its administration and organization. A clear distinction must be made of the kinds of activities appropriate for each type of emergency. The plan must be a flexible tool, but must cover all functional relationships identified, so that services can continue to operate.

Internally, each of the services provided by the hospital will be of greater or lesser importance in the management of an emergency. Indispensable services, by definition, require immediate logistical support, both in terms of human resources and in basic supplies (water, power, food, pharmaceuticals). Non-critical services should be prepared to cede part or all of their personnel and even their facilities, so that they can be temporarily converted into additional emergency treatment areas in disaster situations. Table 4.1 lists typical hospital activities and their relative importance in the event of an emergency.

Table 4.1.
Typical hospital activities and relative importance in an emergency

Clinical and support services	Importance in the event of an emergency
Trauma and Orthopedics	5
Intensive Care Unit / Intensive Treatment Unit	5
Urology	5
Emergency Care	5
Sterilization	5
Diagnostic Imaging	5
Pharmacy	5
Nutrition	5
Transport	5
Recovery	5
Blood Bank	5
Outpatient Consultation/Admissions	4
Pediatric Surgery	4
Pediatrics	4
Laboratory	4
Laundry Services	4
Hemodialysis	4
Internal Medicine	3
Gynecology and Obstetrics	3
Administration	3
Neonatology	3
Respiratory Medicine	2
Neurology	2
Ophthalmology	2
Filing and Case Management	2
Dermatology	1
Psychiatry	1
Oncology	1
Otorhinolaryngology	1
Dental Services	1
Therapy and Rehabilitation	1

Scale of importance:
5:Indispensable 4:Very necessary 3:Necessary 2:Preferable 1:Dispensable

Source: This is a modification of a table prepared by R.Boroschek,et al.in *Capacidad de respuesta de hospitales ante desastres sísmicos:aspectos no estructurales*. International Conference on Disaster Mitigation in Health Facilities,Mexico City, 1996.

External emergencies

As mentioned earlier, a hospital should be able to face a significant natural disaster in its vicinity in such a way that, regardless of the structural and nonstructural damage suffered, its vital operations can continue to function without interruption or with the briefest possible disruption.

The U.S. Veterans' Administration[2] requires that the essential activities of health facilities be able to continue unimpeded for at least three days after a disaster takes place, in order to deal with existing inpatients and handle the injured as a result of the event. In defining essential activities, it is assumed that the hospital structure remains nearly intact and most electrical and mechanical systems still function, albeit with some limitations. Energy, communications and water supply must be guaranteed.

The emergency plan must also contemplate the fact that a natural disaster, particularly a seismic event, is likely to produce certain kinds of injuries, such as fractures, cuts, traumas, lacerations and burns, as well as others related to extreme anxiety such as insulin comas and heart attacks.

Some sources[3] estimate that in the event of a quake roughly 50% of inpatients will have to be transferred to less complex hospital facilities or even back to their own homes. Estimates also suggest that in severely critical situations the hospital might be called upon to expand its care capacity as much as tenfold, depending on the reliability of lifelines such as the water supply system or the medical supplies already stored in the hospital.

The emergency plan must contemplate the conversion of existing facilities for massive emergency care. This of course depends on the physical distribution of the various departments, the availability of equipment and personnel, and the severity of the quake, including the number of victims.

Essential activities in the event of an external emergency

The following is a list of the areas considered essential for caring for the victims of an earthquake (table 4.2). Emergency care, of course, plays the leading role, which may require physical expansion by converting Outpatient Consultation and other nearby areas. The table shows the activities that are directly related to victim management (patient care), support services, and institutional support.

Table 4.2.
Essential activities in the event of an external emergency

Patient care	Medical support	Institutional support
Emergency care	Pharmacy	Command post
Classification of patients	Clinical lab	Maintenance dept.
Immediate ambulatory care	Imaging (X-rays,etc.)	Information services
Non-urgent care / Admittance	Morgue	Nutrition
Surgery	Sterilization	Supplies
Recovery		Storerooms
Intensive care		Communications

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[2] Veterans Administration. *Study of establishing seismic protection provisions for furniture, equipment and supplies for VA Hospitals*. Office of Construction, Washington D.C., 1980.

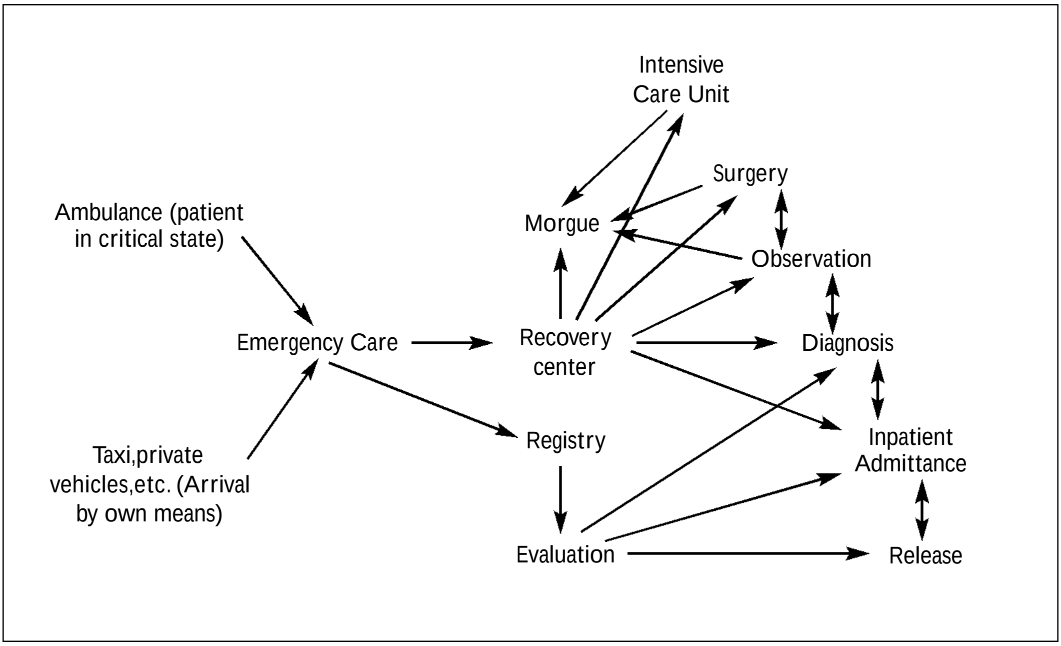
[3] Ibid.

The following section provides a description of how one of these services will function both in its day-to-day operations and in the event of an emergency.[4]

Emergency care

Statistics must be analyzed—or gathered, if currently unavailable—concerning the average number of patients handled by the Emergency Care Unit, including overflow provisions and the availability of a surgical unit exclusively for emergencies, with personnel availability around the clock. Figure 4.2 illustrates the normal flow of patients.

Figure 4.2.
Patient flow in an emergency



The key difference in the event of a disaster is that triage is performed prior to the arrival of patients to Emergency Care, and the successive inflow of patients is determined by their classification. No treatment of any kind is carried out in the triage area. Patients classified as "green" are sent to Outpatient Consultation (expansion area), while "yellow" and "red" patients remain under observation or are sent to Recovery, the Intensive Care Unit, surgery or any other urgent service required.

In the course of the emergency, it is essential for the following services and supplies to be available: lighting and power, water, medicinal gas and the vacuum network (if possible, although individual suction can be used). The communications system is especially important.

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[4] See Cardona, O.D., et. al: *Informe final del proyecto vulnerabilidad funcional y no estructural del Hospital Ramón González Valencia*, Colombia, 1997.

Assessment of essential activities

An example of an assessment of the institutional and logistical support for essential activities required in the event of a massive earthquake can be found in table 4.3. The ratings system work as follows:

- **Optimal**: Efficient allocation of resources or personnel
- **Adequate:** Acceptable allocation of resources or personnel; operations can proceed normally
- **Minimal:** Barely acceptable allocation of resources or personnel; operations can proceed with certain restrictions
- **Inadequate:** Unacceptable assignation of resources or personnel; severe limits on the activity in question, or impossibility of carrying out the activity in question

Table 4.3.
Example of an assessment of institutional/logistical support for key activities

Activity	Support of vital services	Assigned personnel
Emergency Care	Adequate	Optimal
Patient Classification	Adequate	Adequate
Immediate Ambulatory Care	Adequate	Adequate
Non-urgent care	Minimal	Minimal
Surgery Units	Minimal	Adequate
Recovery	Minimal	Minimal
Intensive Care	Minimal	Adequate
Respiratory Therapy	Adequate	Minimal
Pharmacy	Minimal	Adequate
Lab	Minimal	Adequate
Diagnostic Imaging	Minimal	Adequate
Morgue	Minimal	Adequate
Command Post	Minimal	Optimal
Maintenance	Minimal	Adequate
Information Center	Inadequate	Adequate
Nutrition	Inadequate	Minimal
Supplies	Minimal	Adequate
Storeroom/Warehouse	Inadequate	Adequate

Internal emergencies

Internal emergencies can have a variety of causes, such as a minor natural disaster or one caused by human activity that only affects the hospital. Some operational aspects may lead to the functional collapse of the hospital. Consequently, the hospital's organization must have the necessary mechanisms in place to restore normal functioning within a reasonable time.

One tool that must be available in the event of total functional collapse must be an evacuation plan, whether total or partial. Evacuation routes must be properly identified throughout the facilities.

Evacuation is a combination of activities and procedures aimed at preserving the life and well-being of people by means of their orderly flow to lower-risk areas. The decision to evacuate partially or totally must be taken by the hospital director, the head of medical care, the administrator, the head of nursing or the physician in charge. It may also be taken by external personnel, such as firefighters, whose prior knowledge of the hospital's emergency plan, including the key facilities, enables them to play a leadership role when required.

A description of an internal emergency plan and all of its procedures (including warning, execution of plan, care of evacuees, safety and administration) can be found in the specialized literature.[5]

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[5] See for instance: PAHO, *Organización de los servicios de salud para situaciones de desastre* (Publicación Científica No. 443), Washington DC, 1983; PAHO/WHO, *Establecimiento de un sistema de atención de víctimas en masa*, Washington DC, 1996; PAHO/WHO, *Simulacros hospitalarios de emergencia*, Washington DC, 1995.

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Annex*
Methods for the Analysis of Structural Vulnerability

Qualitative and quantitative methods of analysis of varying degrees of complexity exist to determine structural vulnerability, depending on the objective.

Qualitative methods use general characteristics to describe the structure. They are generally associated with universal indices that have been calibrated from damage experienced in existing structures, allowing the identification of risk in general terms and, in some cases, the level of damage. Among these methods, those proposed by Hirosawa[1], Gallegos and Rivers[2], Meli[3], Astroza *et al.*[4] and Shiga[5] merit special mention.

The quantitative methods are based on analyses that are not necessarily more precise. Typically they are extensions of the analysis process and current seismic-resistant design recommendations.

As an example of a preliminary assessment, this Annex gives a brief description of a variation of the Hirosawa method that has been used in countries like Chile, Peru, Mexico and Ecuador. The changes introduced make this methodology valid for the construction styles and materials typically used in Latin American countries.

According to this method, structural vulnerability is determined by comparing:

(a) The strength, configuration of buildings, maintenance and previous damages in the building;

(b) The level of seismic demands on performance of structure, representing the seismic hazard and the local conditions of the site where the building is located.

In the case of the Hirosawa method, the comparison is done by calculating two indices and establishing that the building is seismically safe when the index corresponding to the resistance provided for the building (I_S) is greater than the resistance demanded (I_{SO}).

Hirosawa method

The method proposed by Hirosawa is used in Japan by the Ministry of Construction in the assessment of the seismic safety of buildings made of reinforced concrete. The method recommends three lev-

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* The technical content of the following annex has been taken from the document *"Análisis de vulnerabilidad y preparativos para enfrentar desastres naturales en hospitales en Chile"*, Universidad de Chile. Study made by PAHO/WHO – ECHO, Santiago, Chile, 1996.

[1] Hirosawa, M., *Retrofitting and restoration of buildings in Japan*, IISEE Lecture Note, Seminar Course, Tsukuba, Japan, 1992.

[2] Gallegos, H. and R. Ríos, *Índice de calidad estructural sismorresistente*. 4as Jornadas Chilenas de Sismología e Ingeniería Antisísmica, Volume 2, Viña del Mar, Chile, 1986.

[3] Meli, R., *Diseño sísmico de muros de mampostería, la práctica actual y el comportamiento observado*, Simposio Internacional de Seguridad Sísmica en Vivienda Económica, CENAPRED, Mexico City, Mexico, 1991.

[4] Astroza, M., M.O Moroni and M. Kupfer, *Calificación sísmica de edificios de albañilería de ladrillos confinada con elementos de hormigón armado*. Memorias de las XXVI Jornadas Sudamericanas de Ingeniería Estructural, Vol. 1, Montevideo, Uruguay, 1993.

[5] Shiga, T., Earthquake damage and the amount of walls in reinforced concrete buildings. *Proceedings 6th World Conference of Earthquake Engineering*, New Delhi, India, 1977.

els of assessment that go from the simplest to the most detailed. It is based on the analysis of the seismic behavior of each floor of the building in the main directions of the floor plan.

The method was originally proposed for use in existing or damaged buildings made of reinforced concrete and possessing six to eight floors built with walls or porticos. In more recent studies the method has been applied to buildings made of mixed reinforced concrete and masonry.[6]

Structural vulnerability is established according to the following considerations:

(a) If $I_S \geq I_{SO}$ the building will demonstrate seismically safe behavior in case of a seismic event;

(b) If $I_S < I_{SO}$ the building will demonstrate unstable behavior in case of a seismic event and is, therefore, considered unsafe.

Calculation of the I_S index

This index is calculated using the following equation:

$$I_S = E_O * S_D * T$$

where:

E_O: is the basic seismic index of structural behavior,

S_D: is the index of structural configuration, and

T: is the index of deterioration of the building.

Calculation of E_O

When applying the first level of assessment, the Eo index is determined by the simple calculation of the absolute shearing strength of each floor. This resistance is calculated for each direction of the floor plan by the sum of the product of the area of the cross-section of a wall or column and its shearing strength. This product is then reduced by a factor (α_i) that represents the presence of elements that reach their resistance to a level of deformation that is less than that of the rest of the seismic-resistant elements (e.g., short columns or masonry walls, either reinforced or not, when compared with reinforced concrete walls or columns).

The E_O index is proportional to the product of the resistance coefficient (C) and ductility coefficient (F).

$$E_O \, \alpha \, C * F$$

For the calculation of E_O, all elements or vertical substructures that form part of the seismic-resistant building must be classified under one of the following categories:

i. Short reinforced concrete columns. These are all the columns in which the h_O/D ratio—between the vertical clearance (h_O) and the width of the cross-section (D)—is equal or less than 2. The seismic behavior of these columns is controlled by shearing failure characterized by the low level of resistance to deformation and by the low capacity of inelastic deformation. In order to establish the vertical clearance, due account was given to the presence of architectural elements that reduce the height of the column (i.e., elements that are not isolated from the column).

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[6] Iglesias, J., The Mexico Earthquake of September 19, 1985 – Seminar zoning of Mexico City after the 1985 earthquake, *Earthquake Spectra*, Vol. 5, No1, 1989.

ii. Reinforced concrete columns. These are all the columns in which the h_o/D ratio is greater than 2.
iii. Reinforced concrete walls. These are the reinforced concrete elements with a cross-section in which the relation between the larger side and the smaller side of the cross-section is greater than 3.
iv. Infilled brick walls. These are brick walls, normally with little or no reinforcement, located in openings of the resistant substructure (porticos) without being isolated from them.
v. Reinforced brick walls or brick walls confined with thin elements of reinforced concrete, pillars and framing.

The above-mentioned walls correspond to those that have been designed and constructed in order to transmit horizontal and vertical loads from one level to a lower level and to the foundation. Walls that merely resist loads ensuing from their own weight are not considered, including infilled parapets and partitions or dividing walls that are isolated from the seismic-resistant structure.

This classification must be made to determine resistance and to address the smaller capacity for inelastic deformation and capacity for energy dissipation that some elements display (for example, the short columns and unreinforced, infilled brick walls when they control performance).

The E_o index is calculated by means of the following equation:

$$E_p = \frac{(n_p + 1)}{(n_p + i)} * \{ \alpha_1 * (C_{mar} + C_{sc} + C_a + C_{ma}) + \alpha_2 * C_w + \alpha_3 * C_c \} * F$$

where:

α_1: reduction factor of the resistant capacity in accordance with the deformation level at which the elements that control seismic behavior resist.[7] The values of these factors are given in table A1 when the seismic capacity is controlled by the weakest elements (Type A), less weak elements (Type B) and ductile elements (Type C), respectively

N_p: number of floors in the building

i: the level under assessment

C_{mar}: the resistance index exhibited by the infilled brick walls

C_{sc}: the resistance index exhibited by the short reinforced concrete columns

C_a: the resistance index exhibited by the unreinforced or partially confined brick walls

C_{ma}: the resistance index exhibited by the confined brick walls

C_w: the resistance index exhibited by the reinforced concrete walls

C_c: the resistance index exhibited by the reinforced concrete columns that are not short

F: the ductility index associated with the vertical elements

$F = 1.0$ if C_{mar}, C_a and C_{sc} are equal to zero

$F = 0.8$ if C_{mar}, C_a and C_{sc} are not equal to zero

In case the confined brick walls control the resistant capacity, the value of F is equal to 1.0 considering the capacity for inelastic deformation that is obtained with the confining elements.

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[7] Murakami, M., K. Hara, H. Yamaguchi, S. Shimazu, Seismic capacity of reinforced concrete buildings which suffered the 1987 Chibaken-toho-oki earthquake, *Proceedings 10th World Conference of Earthquake Engineering*, Madrid, Spain, 1992.

Seismic capacity must be calculated first by considering the failure of the weakest elements. Nevertheless, if the failure of this group does not produce instability in the system, seismic capacity must be calculated by considering the next group and rejecting the resistance of the elements that have failed.

Table A1.
Values of the coefficients α_i

Type	α_1	α_2	α_3	Failure
A	1.0	0.7	0.5	Infilled brick walls or short columns or non-reinforced and partially confined brick walls or confined brick walls control failure.
B	0.0	1.0	0.7	Reinforced concrete walls control failure.
C	0.0	0.0	1.0	Reinforced concrete columns control failure.

The term (n + 1)/(n +i) refers to the relation between the coefficient of basal shearing and the coefficient of shearing of floor i, when these shearing forces are established as a function of the weight of the building divided by the level being considered.

The resistance indices (C_i) were determined based on the strengthening characteristics of the reinforced concrete walls constructed in Chile (quantity and means of reinforcement), which incorporates changes in the figures proposed by Hirosawa and Iglesias. For the brick walls, the resistance proposed by Iglesias for infilled walls (diaphragm-type walls) and the resistance of diagonal cracking recommended by Raymondi[8] for confined brick walls were utilized.

The equations used were:

$$C_{mar} = \frac{0.6 * 0.85 * \tau_o * \sum A_{mar}}{\sum_{j=i}^{n_p} W_j}$$

$$C_{sc} = \frac{f_c}{200} * \frac{15 * \sum A_{sc}}{\sum_{j=i}^{n_p} W_j}$$

$$C_{mar} = \frac{0.6 * (0.45 * \tau_o + 0.25 * \sigma_o) * \sum A_{ma}}{\sum_{j=i}^{n_p} W_j}$$

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[8] Raymondi, V. , *Anteproyecto de norma de diseño y cálculo de albañilería reforzada con pilares y cadenas*, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile, 1990.

$$C_a = C_{ma}$$

$$C_w = \frac{f_c}{200} * \frac{30 * \sum A_{m_1} + 20 * \sum A_{m_2} + 12 * \sum A_{m_3} + 10 * \sum A_{m_4}}{\sum_{j=i}^{n_p} W_j}$$

$$C_c = \frac{f_c}{200} * \frac{10 * \sum A_{c_1} + 7 * \sum A_{c_2}}{\sum_{j=i}^{n_p} W_j}$$

where:

f_c = Cylindrical resistance to compression exhibited by the concrete.

$\sum A_{mar}$ = Sum of the areas of the infilled brick walls on the floor under assessment in the direction under analysis.

$\sum A_{sc}$ = Sum of the area of short reinforced concrete columns on the floor under assessment.

$\sum A_{ma}$ = Sum of the areas of the confined brick walls on the floor under assessment in the direction under analysis.

$\sum A_{m_1}$ = Sum of the areas of the reinforced concrete walls on the floor under assessment with columns in both ends, with horizontal reinforcement greater than or equal to 1.2 % and wall thinness (HIL) greater than 2. In these walls the resistance to shearing is controlled by the resistance to crushing of the compressed diagonal due to the high level of horizontal reinforcement.[9]

$\sum A_{m_2}$ = Sum of the areas of the reinforced concrete walls on the floor under assessment with columns in both ends and a minimal amount of horizontal reinforcement. In these walls the resistance to shearing is provided mainly by the horizontal reinforcement.[10]

$\sum A_{m_3}$ = Sum of the areas of the reinforced concrete walls on the floor under assessment, without columns or with a column in some of its ends, a wall thinness less than or equal to 2 and minimum reinforcement. In these walls, the resistance to shearing is defined by the diagonal cracking load of the concrete due to its reduced level of reinforcement.[11]

$\sum A_{m_4}$ = Sum of the areas of the reinforced concrete walls on the floor under assessment, without columns or with a column in some of its ends and a wall thinness greater than 2. In these walls the resistance to shearing is provided by the ACI-318 standard equations.[12]

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[9] Wakabayashi, M., *Design of earthquake-resistant buildings*, Mc Graw-Hill Book Company, 1986.

[10] Ibid.

[11] Ibid.

[12] ACI 318 (1984) "Building Code Requirements for Reinforced Concrete."

$\sum A_{c_1}$ = Sum of the areas of the reinforced concrete columns[13] where the relation between the vertical clearance (h) and the width (D) is less than 6.

$\sum A_{c_2}$ = Sum of the areas of the reinforced concrete columns[14] where the relation between the vertical clearance (h) and width (D) is equal to or greater than 6.

W_j = Weight of floor j.

τ_o = Basic resistance to shearing of masonry.

σ_o = Normal stress due to axial force produced by the weight of vertical loads and overloading.

L = Length of the wall.

H = Height of the floor if L is greater than or equal to 3 m, or the vertical clearance of the wall if L is less than 3 m.

In these equations the areas must be expressed in cm^2, the resistance and stress in kgf/cm^2 and weight in kg. The coefficients that accompany the areas correspond to the resistance to shearing exhibited by the different types of elements that form the seismically resistant system. The value of these coefficients is expressed in kgf/cm^2.

Calculation of S_D

This coefficient quantifies the influence of irregularities in the structural configuration and the distribution of stiffness and mass on the seismic behavior of the building.

Information needed to calculate S_D is obtained mainly from structural plans and is complemented by on-site visits. The characteristics of a building considered in the determination of this coefficient are: regularity of the floor plan, the length-width relation of the floor plan, contraction points in the floor plan, thickness of the expansion joints, dimensions and location of inner patios, existence of a basement, uniformity of height of the floors, eccentricity in the stiffness of the floor plan, irregularities in the distribution of mass, stiffness of the mezzanine of higher floors, etc.

Hirosawa proposes the following equation to calculate S_D when the first level of assessment of vulnerability is used:

$$S_D = \prod_{i=1}^{1=8} q_i$$

where:

$$q_i = \{1.0 - (1 - G_i) * R_i\} \text{ when } i = 1, 2, 3, 4, 5, 7 \text{ and } 8$$

$$q_i = \{1.2 - (1 - G_i) * R_i\} \text{ when } i = 6$$

The values of G_i and R_i recommended by Hirosawa are shown in table A2.

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[13] Hirosawa, M. (1992) "Retroffiting and Restoration of Buildings in Japan" IISEE, Lecture Note of Seminar Course, Tsukaba, Japan.

[14] ACI 318 (1984) “Building Code Requirements for Reinforced Concrete”.

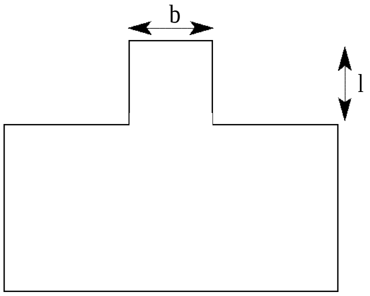
Table A2.
Values of Gi and Ri

ITEMS	**G_i**			**R_i**
(q_i)	**1.0**	**0.9**	**0.8**	
1.Regularity	Regular (a_1)	Median (a_2)	Irregular (a_3)	1.0
2.Length-width ratio	$B \leq 5$	$5 < B \leq 8$	$B > 8$	0.5
3.Contraction of the plan	$0.8 \leq c$	$0.5 \leq c \leq 0.8$	$c < 0.5$	0.5
4.Vestibule or interior patio	$R_{ap}= 0.1$	$0.1 < R_{ap} \leq 0.3$	$0.3 < R_{ap}$	0.5
5.Eccentricity of the vestibule or interior patio	$f_1 = 0.4$ $f_2 = 0.1$	$f_1 \leq 0.4$ $0.1 < f_2 \leq 0.3$	$0.4 < f_1$ $0.3 < f_2$	0.25
6.Basement	$1.0 \leq R_{as}$	$0.5 \leq R_{as} < 1.0$	$R_{as} < 0.5$	1.0
7.Expansion joint	$0.01 \leq s$	$0.005 \leq s < 0.01$	$s < 0.005$	0.5
8.Uniformity of height of floor	$0.8 \leq R_h$	$0.7 \leq R_h < 0.8$	$R_h < 0.7$	0.5

Following is the description of each one of the characteristics.

1. **Regularity a_i**

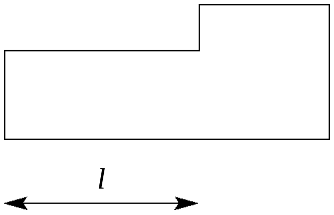
a_1: The floor plan is symmetrical in each direction, and the area of projections is less than or equal to 10% of the total area of the plan. These projections are considered where $l/b \geq 0.5$.

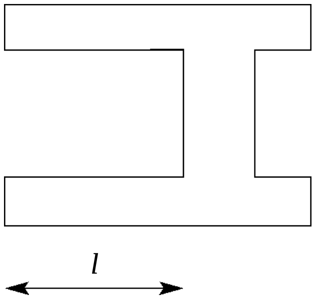


a_2: The plan is irregular, and the area of projections is less than or equal to 30% of the total area of the plan. This includes plans with L, T, U, and other shapes.

a_3: The floor plan is more irregular than in a_2, and the area of projections is greater than 30% of the area of the floor plan.

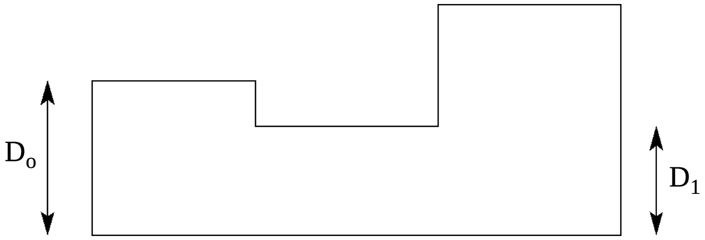
2. **Length-width ratio, B:**
   Ratio of the greater and lesser dimensions of the floor plan.
   In floor plans of type L, T, U and others, the longer side is considered 2*l, with l shown in the figure below.





3. **Contraction of the floor plan, c:**

$$c = \frac{D_1}{D_o}$$



4. **Vestibule or inner patio, R_{ap}:**
   This is the ratio of the area of the vestibule or patio to the total area of the plan, including the area of the patio/vestibule. Nevertheless, a flight of stairs constructed with reinforced concrete walls is not considered in this analysis.

5. **Eccentricity of vestibule or inner patio, *f*:**
   f_1: Ratio of the distance from the center of the floor plan to the center of the vestibule, and the shorter length of the floor plan.
   f_2: Ratio of the distance from the center of the floor plan to the center of the vestibule, and the greater length of the floor plan.

6. **Basement, R_{as}:**
   Ratio of the mean area of the floor plan of the basement levels to the mean area of the building's floor plan.

7. **Expansion joints, *s*:**
   This criterion is applied to buildings that have expansion joints. It is the ratio of the thickness of the seismic expansion joints to the height where the joints are located.

8. **Uniformity of height of floor, R_h:**
   Ratio of the height of two contiguous floors (height of the floor above the floor under analysis to the height of the floor being considered). For the case of the highest floor, the floor immediately above in this ratio is replaced by the floor immediately below.

According to Hirosawa, the value of S_D is calculated by using the least favorable value among those obtained for the characteristics of different floors, a value that is assumed to be representative of the entire building.

Calculation of T

This index quantifies the effects produced by the deterioration of the building over time, effects of previous earthquakes or other events. The index is calculated from information obtained from on-site visits and from the information provided by the owner.

The index T is determined using table A3. When a unique value for T is used for the building, this value must correspond to the smaller value obtained in table A3.

Table A3.
Values of the index T for different causes and types of deterioration

Permanent deformation (T_1)	
Characteristics	**T_1**
The building is leaning due to differential settling	0.7
The building is constructed on landfill	0.9
The building has been repaired due to previous deformations	0.9
Visible deformation of beams or columns	0.9
Does not exhibit any signs of deformation	1.0

Cracks in walls or columns due to corrosion of the reinforced steel (T_2)	
Characteristics	T_2
Signs of leaking with visible corrosion of reinforcement	0.8
Visible slanted cracks in columns	0.9
Visible cracks in walls	0.9
Signs of leaking but without corrosion of reinforcement	0.9
None of the above	1.0

Fires (T_3)	
Characteristics	T_3
It has undergone fire but was not repaired	0.7
It has undergone fire and was suitably repaired	0.8
Has not undergone fire	1.0

Use of the body or block (T4)	
Characteristics	T4
It stores chemical substances	0.8
Does not contain chemical substances	1.0

Type of structural damage (T_5)	
Characteristics	T_5
Severe structural damage	0.8
Major structural damage	0.9
Slight structural damage or nonstructural damage	1.0

The criterion for the classification of earthquake damage is shown in table A4.

Table A4.
Classification of damages caused by earthquake

Type of damage	*Description*
Non-structural	Damage only in non-structural elements
Light structural damage	Cracks less than 0.5 mm wide in reinforced concrete elements. Cracks less than 3 mm wide in masonry walls
Major structural damage	Cracks 0.5 to l mm wide in reinforced concrete elements. Cracks 3 to 10 mm wide in masonry walls.
Severe structural damage	Cracks more than 1 mm wide in reinforced concrete elements. Openings in masonry walls.Collapse of concrete, breakage of stirrups and buckling of reinforcement in beams,columns and walls of reinforced concrete.
Cracking of capitals and consoles	Collapse of columns.Collapse of more than 1% of building height.Building settles more than 20 cm.

Source: Iglesias,J.,The Mexico Earthquake of September 19,1985 – Seminar zoning of Mexico City after the 1985 earthquake, *Earthquake Spectra*,Vol.5,No1,1989.

Calculation of index I_{SO}

This index is calculated using the following equation:

$$I_{so} = E_{so} * Z * G * U$$

where:

E_{SO} = Required basic seismic resistance

Z = Seismic zone factor; its value depends on the seismic hazard of the place where building is located ($0.5 \leq Z \leq 1$)

G = Influence of the topographical and geotectonic conditions

U = Importance of building according to its use

Basic seismic resistance (E_{SO}) was determined based on the study of building damage during an earthquake.[15] For the purpose of other studies, it is recommended that this resistance be established based on requirements for elastic strength under the current norms in the greatest seismic hazard zone (epicenter), reduced by a factor of reduction (R) whose value must be determined given that the damage does not impede function of the facility.

Factor G is equal to 1.0 for topographical conditions without slope, and is equal to 1.1 for zones with slope.[16]

The importance factor, U, is equal to 1.0 given that the required conditions for use of the building are considered when establishing the value of E_{SO}.

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[15] Hirosawa, M., "Retrofitting and Restoration of Buildings in Japan". IISEE Lecture Note, Seminar Course, Tsukuba, Japan, 1992.

[16] Ibid.

In a period of only 15 years, between 1981 and 1996, 93 hospitals and 538 health care centers in Latin America and the Caribbean were damaged as a consequence of natural disasters. This resulted in the loss of service of some 24,000 beds. The direct cost of these disasters has been enormous; just as devastating has been the social impact of the loss of these critical facilities at a time when they were most needed.

Hospitals and health centers are complex; they have high occupancy levels and play a critical role in disaster situations. For these reasons, special consideration must be given to disaster planning for these facilities. Assessing and reducing their vulnerability to natural hazards is indispensable.

Principles of Disaster Mitigation in Health Facilities is an updated compilation of various documents on the topic already published by PAHO/WHO. Sections of previous publications have been revised to address the needs of professionals from a variety of disciplines, particularly those involved in health facility planning, operation and maintenance. It does not attempt to address the more technical and specialized aspects of disaster mitigation. Figures and photographs illustrate situations that can increase disaster vulnerability in health facilities. Examples are given of how countries in Latin America have conducted vulnerability assessments and applied specific disaster mitigation measures in their hospitals and health centers.

The book focuses on problems encountered in areas at high risk for seismic events. It introduces the essential aspects of carrying out vulnerability assessments and applying practical measures to mitigate damage in hospitals, addressing structural and nonstructural aspects, as well as administrative and internal organization.

Also published by PAHO/WHO:

Natural Disaster Mitigation in Drinking Water and Sewerage Systems—Guidelines for Vulnerability Analysis, Washington, D.C., 1998

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